# The effect of simulated winter warming spells on Canada fleabane [*Conyza canadensis (L.) Cronq. var. canadensis*] seeds and plants

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This is an Accepted Manuscript of an article published by Canadian Science Publishing in the Canadian Journal of Plant Science on February 5, 2014, available online: https://doi.org/10.1139/CJPS2013-302

**Suggested Citation**: Tozzi, E., Lyons, E. M. and Van Acker, R. C. 2014. The effect of simulated winter warming spells on Canada fleabane [*Conyza Canadensis* (L.) Cronq. var. *canadensis*] seeds and plants. Can. J. Plant Sci. 94: 963-969. https://doi.org/10.1139/CJPS2013-302

# The effect of simulated winter warming spells on Canada fleabane [*Conyza canadensis* (L.) Cronq. var. *canadensis*] seeds and plants

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**Abstract**: Experiments were establish at three sites in southern Ontario, Canada in 2009 and 2010 to determine the possible effect of winter warming spells applied in either January, February or March on seed, seedlings, or rosettes of Canada fleabane including effects on winter survival, fecundity, above-ground biomass, and flowering timing. Warming spells reduced survival of fall-established rosettes and fall established seedlings. Warming spells occurring late in winter (March) had a greater effect where March warming spells reduced the survival of rosettes and seedlings on average by 53% and 80%, respectively. In addition, overwintering Canada fleabane plants (rosettes or seedlings) exposed to warming spells flowered earlier (between 29 and 71 days earlier). This study also confirms that Canada fleabane seed has little or no dormancy and that the great majority of seed recruits (either in fall or spring) within a given season (between 84% and 93%). We also determined that timing of seed shed in the fall significantly affects the proportion of seedlings emerging either in the spring or fall with late shed favoring seed overwintering and spring seedling emergence. The results of this study suggest that winter warming spells, especially later in the winter (into early spring), may limit the success of Canada fleabane and in particular its success as a winter annual.

**Key words**: Recruitment, facultative winter annuals, warming spells, climate change, *Conyza Canadensis*

## Introduction

Understanding the recruitment nature of facultative winter annual weeds such as Canada fleabane [*Conyza canadensis* (L.) Cronq. var. *canadensis*] can provide insight into their population dynamics and management. Facultative winter annual weeds can germinate mostly in the fall, mostly in the spring, or equally in both seasons (Zahra-Hosseini and Van Acker 2009). Canada fleabane is a surface-germinating ruderal facultative winter annual with recruitment that is highly susceptible to changes in microsite conditions (Regehr and Bazzaz 1979; Buhler and Owen 1997; Main et al. 2006; Nandula et al. 2006). The formation of an overwintering rosette allows Canada fleabane to capture resources (in late fall and early spring) while most competitors are non-existent. In Ontario, Canada, fleabane flowers and sets seed in the late summer and fall with seed germinating to form a seedling or rosette, and some seed not germinating. Canada fleabane seed can also overwinter and germinate in the spring, producing seedlings that sometimes do not form a rosette (Regehr and Bazzaz 1979). Nandula et al. (2006) determined that the ideal seed germination conditions for Canada fleabane were disturbed moist soil with 248C/208C daynight cycles with 13-h day-length periods and that any changes to these conditions can have an impact on successful seedling recruitment. The lack of seed dormancy and indeterminate flowering period for Canada fleabane suggest that microsite conditions play a large role in recruitment timing and perhaps overwintering biology (Regehr and Bazzaz 1979). The ability to recruit in either spring or fall highlights how important our understanding of these factors is to the relative success of this species, its competitiveness in certain farming systems, and to approaches for management.

Rosette survival over winter is affected by a variety of conditions including frost heaving, which occurs commonly in the siltloam soils preferred by Canada fleabane (Regehr and Bazzaz 1979). Frost heaving accounted for up to 86% mortality in a naturally established Canada fleabane population in Urbana, Illinois, affecting smaller rosettes more than larger rosettes (Regehr and Bazzaz 1979). The frequency of frost heaving increases with fluctuating temperatures in late fall or early spring (Taber 1929) and may be facilitated by warming spells in the winter or spring.

Winter warm spells are defined as periods of consecutive temperatures in the 80th percentile of average temperatures (Shabbar and Bonsal 2003). Accordingly, longer warm spells (≥3 d) in one region of northern North America (southern Ontario, Canada) occur once every 10 yr, but the frequency, duration, and severity of warm spells is expected to increase as global climate change progresses (Shabbar and Bonsal 2003). Three days was found to be the minimum time needed for a warming spell to produce influential results on the localized environment (Shabbar and Bonsal 2003). Shorter warm spells (1 or 2 d) are even more frequent and may still affect the winter survival and spring emergence of ruderal winter annual species such as Canada fleabane given that seed germination is greatly influenced by microsite changes. Warm spells may affect seed microsite conditions and temporarily create sites suitable for seed germination. The influence of warm spells may be especially important for opportunistic facultative winter annual ruderal weed species such as Canada fleabane.

Low temperatures keep Canada fleabane rosettes from initiating vertical growth (bolting) and seed from germinating throughout the winter period (Regehr and Bazzaz 1979). Short periods of warm temperatures in the winter, or warming spells, could affect critical elements of population dynamics including the survival of rosettes and the viability of seed over winter. Warm spells may also affect spring seed germination and spring seedling recruitment, which could shift the relative spring versus fall emerging proportions of given Canada fleabane populations (Regehr and Bazzaz 1979).

The objective of this study was to determine the effect of warming spells on fecundity, above-ground biomass, flowering timing, overwintering survival, and fate of seed in Canada fleabane. The results of this study will provide insight into the possible impact of one aspect of climate change, warming spells, on the population dynamics of this species and the management implications.

## Materials and Methods

The intent of this study was to explore the effect of warming spells on the whole population dynamic of Canada fleabane and as such we investigated the effect on rosettes (established in the fall and overwintering), seed (shed late in the fall and overwintering) and seedlings (emerging in the late fall or spring). To provide a robust assessment of effects we measured winter survival (to bolting in the following summer) of fall established rosettes and seedlings and survival to bolting of spring seedlings, fate of seed shed in the fall, and growth, flowering timing and fecundity of overwintering rosettes and of seedlings emerging in either fall or spring. Experiments were established at three sites in each of two seasons (fall through to summer of 2009-2010 and 2010-2011) in a region of south central Ontario, Canada (sites were located near the towns of Woodstock, Simcoe and Guelph). The Woodstock site was situated on a Guelph Loam series soil (Gray Brown Luvisol) containing 35% sand, 52% silt, 13% clay, 3.6% organic matter, with a pH of 6.4. The Simcoe site was situated on a Berrien sandy-loam soil containing 55% sand, 30% silt, and 15% clay, 1.93% organic matter, with a pH of 6.8. The Guelph site was situated on a very fine sandy loam soil containing 58% sand, 31% silt, 10% clay with a neutral pH. All experiments were conducted using a pool of seeds collected from these three locations in 2009 and 2010. Seeds were collected from fully mature plants in mid-October each year at all sites. Micro-perforated plastic bags (30 cm wide by 100 cm long) were placed over each plant before any seed shed occurred to maximize seed capture. When flowering and seed set had ceased, the flowering parts of the plant were cut with the bag still attached and these were placed into large paper bags. Seeds were threshed by banging the flowering stalks against the inside of the paper bag. All seeds were combined each year to mitigate any population-site differences and stored at 4ºC until needed.

## Fall Rosettes

To investigate the impact of warming spells on fall-established rosettes, four warming spell treatments including a control (no warming spell) were used. We also included two seeding date treatments (early and late fall). A quantity of Canada fleabane seed large enough to provide enough plants for the experiment was germinated indoors in trays containing a potting mix (Pro-Mix) soil under 16 h of daylight at 22ºC. One cohort of seeds was germinated in mid-August to simulate early seed shed, while another was germinated in late September to simulate late seed shed. Rosettes were grown to approximately 8 cm in diameter (5-6 wk) and were then transplanted into 96 small rubberized plastic tubs (40 cm x 25 cm x 30 cm) with two rosettes per tub. The plastic tubs ensured ease of removal from the ground when it came time for transfer of plants to growth chambers to simulate warming spells. Thirty-two tubs were used at each of the three sites in each season.

The tubs for each site had holes drilled in the bottom for drainage and were filled with soil collected from each respective site. The rosettes were no larger than 9 cm in diameter when they were placed outside. Main et al. (2006) reported that rosettes larger than 9 cm had increased mortality. Trenches measuring 3 m long, 0.5 m wide, and 0.3 m deep were dug into the soil at each site to house the tubs. Tubs containing the early seed shed rosettes (early) were placed outdoors in mid-September, whereas tubs containing the late seed shed rosettes (late) were placed outdoors in mid-October. The tubs were organized in a completely randomized design with four replicates per treatment per site.

To simulate warming spells, eight tubs at each site (representing four replicates of each of the early- or late-seeded treatments for one warming spell timing) were removed at one of three periods throughout the winter (either mid-January, mid-February or mid-March). At each site, a set of control treatment tubs were left in the ground for the duration of the experiment and not exposed to any warming spell treatment. Different tubs were removed from each site for each warming spell treatment. These tubs were transported by hand to a growth chamber set to represent warming spell conditions. Chamber temperatures for a given warming spell treatment were based on a warming spell definition from Shabbar and Bonsal (2003) and were set as 3 d of consecutive temperatures in the 80th percentile of average temperatures for each site for the days of year for each specific warming spell period (mid-January, mid-February or mid-March) based on long-term weather data for each site (Table 1). After each warming spell treatment, tubs were returned to their respective outdoor sites.

Fecundity was determined by multiplying the average number of seeds per flower by the number of flower heads on each plant (counted late in each season). Average number of seeds per flower was determined by counting the number of seeds per capitula in 50 capitula from surviving plants chosen at random from within each of the three experiment sites each year. Survival was measured as the number of plants that survived to bolting. Above-ground dry biomass was measured by harvesting plants at soil level, drying them at 105ºC for 72 h, and weighing them. Given the indeterminate nature of Canada fleabane, flowering timing was recorded as date of first seed shed.

Table 1. Conditions in growth cabinets for 3-d simulated warming spell treatments imposed on Canada fleabane seeds, seedlings and rosettes. Refer to Materials and Methods for explanation of determination of warming spell treatment conditions

| **Month of warming spell** | **Temperature (ºC day/night)** | **Relative humidity (%)** | **Photoperiod (h day/night)** |
|---|---|---|---|
| January | 7/5 | 80 | 9/15 |
| February | 7/5 | 80 | 10/14 |
| March | 13/8 | 80 | 11/13 |

## Seeds and Seedlings

To investigate the effect of warming spells on the fate of seed (shed in the fall) and seedlings emerging either in fall or spring, freshly collected Canada fleabane seed (pooled among collection sites) was placed outside in plastic containers at each site in the fall of 2009 and 2010. Containers measured 15 cm long x 10 cm wide x 5 cm deep (each container was considered an experimental unit). These were filled with soil from each respective site and there were 100 seeds per container. Containers were set outside at each site at two dates, mid-September and mid-October in each year with 24 containers (3 replicates x 4 warming spell treatments x 2 seeding depths) set out at each date at each site in each year. The two seeding depths were soil surface or just below the soil surface (0.5 cm deep). These treatments allowed us to investigate whether shallow seed burial would affect seed recruitment timing. Containers were arranged in a completely randomized design at each site. At each warming spell date, six containers from each site were subjected to a simulated warming spell following the methods described above for the rosette study. Seedling emergence from the containers was recorded in the fall and spring by counting the number of seedlings emerged each week in each container from mid-August to mid-November in the fall and from the beginning of April to mid-July in the spring. In the spring, seedlings that emerged late in the fall (not forming a rosette) and overwintered or seedlings that emerged in the spring were monitored through the season to determine survival (survival to bolting) and flowering timing.

### Statistical Analysis

Statistical analysis was conducted using JMP 9.0.2 software (SAS Institute, Inc. 2010. SAS Campus Drive, Cary, NC 27513). All data were subjected to an ANOVA using a linear mixed effects model with date of warming spell (fixed), site (random), year (random), and early/late seeding (fixed) as factors, and with replication nested in site for fecundity (capitula/plant), above-ground biomass (g at flowering stage), survival (% at bolting stage), and flowering timing (first seed shed). On the basis of an examination of residual plots, data were deemed to meet the assumptions of ANOVA including homogeneity of variance. For fecundity, above-ground biomass, and survival; site, year, seeding date, and block were all found to not be significant and there were no significant interactions between these factors. As such, data were pooled across these factors for subsequent ANOVA. Similarly, we were able to pool data for flowering date over site, seeding date, and block. In all cases, means were considered significantly different on the basis of $P < 0.05$ using Tukey's HSD.

## Results

### Rosettes

For rosettes of Canada fleabane established indoors and placed outside in the fall of 2009 and 2010, simulated warming spells did impact survival ($P < 0.001$), growth (above-ground dry biomass) ($P < 0.001$) and fecundity ($P < 0.0107$). Means of these factors differed significantly depending on the timing of warming spells (Table 2). There was significantly less survival in both years for rosettes that were subjected to warming spells compared with controls (no imposed warming spells) and rosettes that were exposed to warming spells in March had significantly lower survival levels versus those exposed to warming spells in either January or February (Table 2). The March warming spell reduced survival of Canada fleabane rosettes on average by almost 50% on average (Table 2).

For rosettes of Canada fleabane established indoors and placed outside in the fall simulated warming spells did significantly impact flowering date ($P < 0.0428$) (Table

2). The rosettes subjected to a March warming spell flowered on average 62 d earlier than rosettes not subjected to any warming spell (the control treatment). Rosettes that were subjected to a February warming spell flowered 37 d earlier on average than rosettes in the control treatment and those subjected to a warming spell in January showed numerical but not significantly earlier flowering timing (Table 2).

## Seeds

For seeds of Canada fleabane that were placed outside in the fall of 2009 and 2010 but that did not germinate in the fall to produce seedlings (and as such overwintered as seed) there was no effect of warming spell treatments on the survival (to bolting) and flowering date of seedlings emerging from these seeds in the spring (Table 3). However, time of seeding (early vs. late fall) and depth (soil surface vs. 0.5 cm) did have significant effects on total (fall plus spring) germination levels (Table 3). In the fall, significantly more seed germinated in the early versus the late-seeded treatments. In the spring, the opposite was true and more seedlings emerged from the late- versus the early-seeded treatments. There was some interaction with seeding depth in this respect, where, in three of four cases, seed burial encouraged greater overwintering seed persistence and subsequent germination in the spring, in particular for the late seeding date (Table 3).

Total percent germination of Canada fleabane seed was very high in this study ranging from 83.5 to 92.9% (Table 3) and very little seed did not germinate. This supports the notion that Canada fleabane supports only a small seed-bank and is a seed-limited species (Van Acker 2009) and it corroborates the results of other studies. Davis et al. (2009), for example, measured a 76% decrease in the seed-bank of Canada fleabane after 10 mo and Thebaud et al. (1996) determined that only 1% of Canada fleabane seed remained viable after 3 yr on the soil surface.

Table 2. Effect of simulated warming spell dates (WSD) in January, February, and March on fecundity (capitula/plant), above-ground biomass (g at flowering stage), survival (% at bolting stage), and flowering date (first seed shed) for Canada fleabane rosettes established in the fall of 2009 and 2010 at three sites in southern Ontario, Canada

| WSD | Fecundity[z] (capitula/plant) | Dry weight[z] (g) | Survival[z] (%) | Flowering date 2010 | Flowering date 2011 |
|---|---|---|---|---|---|
| Control | 940*a* | 54.0*a* | 88.5*a* | 246*a* | 260*a* |
| Jan | 889*ab* | 51.3*ab* | 82.3*ab* | 229*ab* | 248*a* |
| Feb | 777*bc* | 50.4*ab* | 75.0*b* | 212*b* | 223*ab* |
| March | 739*c* | 48.8*b* | 46.9*c* | 171*c* | 198*b* |

[z] Data pooled over years.

*a-c* Means within columns followed by different letters denote significant differences at $P < 0.05$.

## Seedlings

For seedlings that were established in the fall from seed placed outside in the fall of 2009 or 2010, timing of warming spell (month) did have a significant negative effect on overall seedling survival and flowering timing ($P < 0.0001$) (Table 4). A March warming spell reduced survival of fall established seedlings by 80% coming from surface-placed seed and by 96% for seedlings coming from seed placed at 0.5-cm depth, whereas a February warming spells reduced survival by 55% for surface placed seed and 88% for seedlings coming from seed at the 0.5-cm depth. For January warming spells (37% reduction in survival seedlings from surface placed seed and 66% for seedlings from seed at the 0.5-cm depth) seedling survival did not significantly differ from the seedlings in the control treatment. There was no significant effect of date of warming spell (month) on flowering date for seedlings emerging in the spring (Table 5), showing that the warming spell effect on flowering did not occur when the warming spell was imposed on the seeds. Seedlings emerging in the fall from seeds placed in trays outside in the fall that overwintered and were subjected to a March warming spell, flowered on average 71 d earlier than the control seedlings while similar seedlings exposed to a February warming spell flowered on average only 29 d earlier than the control seedlings (Table 4). Depth of seeding had a significant effect on seedling survival ($P < 0.0292$) with greater survival for seedlings establishing from seeds on the soil surface (Table 4).

Table 3. Average total germination (per 100 seeds) in fall or spring and total percent germination of Canada fleabane seed, seeded either early in fall (September) or late

(October) either on the soil surface or just below the surface (0.5 cm) in 2009 and 2010 at three sites in southern Ontario, Canada

| Treatment | Fall 2009[z] | Spring 2009[z] | Total (%) | Fall 2010[z] | Spring 2010[z] | Total (%) |
|---|---|---|---|---|---|---|
| Early (0.0 cm) | 52.2*a* | 36.2*a* | 88.3 | 64.2*a* | 26.9*b* | 91.1 |
| Early (0.5 cm) | 44.3*ab* | 43.8*a* | 88.2 | 66.2*a* | 26.7*b* | 92.9 |
| Late (0.0 cm) | 60.0*a* | 30.3*a* | 90.3 | 43.0*b* | 47.5*a* | 90.5 |
| Late (0.5 cm) | 38.4*b* | 45.1*a* | 83.5 | 37.5*b* | 50.2*a* | 87.7 |

[z] Data pooled over sites within year.

a, b Means within columns followed by different letters denote significant differences at $P < 0.05$.

## Discussion

The effect of warming spells on the survival of Canada fleabane rosettes may have resulted in part from the effects that warming spells can have on the surrounding environment, including the facilitation of frost heaving. Frost heaving can occur during periods of fluctuating freezing and thawing. Frost heaving can rip the root system of the rosettes apart or uproot the entire plant causing mortality (Jonasson 1986). Regeher and Bazazz (1979) have previously shown that frost heaving may cause significantly higher levels of mortality in Canada fleabane rosettes. Warming spells can exacerbate frost heaving by providing rapid thawing periods, followed by a return to freezing temperatures once the warming spells has passed. In our study, mortality increased significantly when the warming spell was closer to spring when temperature fluctuations tend to be greater and frost heaving is more likely (Taber 1929).

Warming spells also subjected the rosettes to rapidly increasing and decreasing temperatures over a relatively short period. Both an increase and a decrease in external temperatures places stresses on rosettes evoking an acclimatization response (Gilmour and Thomashow 1991; Holt 1995; Thomashow 1999). The acclimatization response period of Canada fleabane to these types of temperature stresses is not known, but plants exposed to a cold acclimation period can be more tolerant to freezing than plants that have experienced a cold shock (Kalberer et al. 2006). In this study, the rosettes exposed to the March warming spells may have begun a spring acclimatization process since March air and soil surface temperatures are significantly higher than in January or February in this region (Holt 1995). A warming spell in March may initiate an acclimatization response at a higher energy cost that may lead to increased mortality when plants are returned to cold temperatures (Dulai et al. 1998; Saarinen et al. 2011). The plants would experience an increase of ~10-15ºC during these warming spell periods, depending on the daily weather.

Table 4. Effect of simulated warming spell dates (WSD) in January, February, and March and seeding depth (cm) on seedling survival (% at bolting stage) and flowering date (first seed shed) for seedlings recruiting in the fall from Canada fleabane seeds (from southern Ontario populations) seeded outside at three sites in southern Ontario in the fall of 2009 and 2010

| WSD | Flowering date[z] | Survival[z] (%) 0.0 cm | Survival[z] (%) 0.5 cm |
|---|---|---|---|
| Control | 246*a* | 68.3*a* | 35.8*a* |
| Jan | 244*ab* | 63.4*ab* | 33.7*a* |
| Feb | 217*bc* | 45.8*b* | 22.5*ab* |
| March | 175*c* | 20.0*c* | 3.33*b* |

[z] Data pooled over years.

a-c Means within columns followed by different letters denote significant differences at P < 0.05.

In addition, Canada fleabane has been shown to have a remarkably rapid photosynthetic response rate even in the winter if there is sufficient light (Regeher and Bazzaz 1976, 1979). In this study, more than 10 cm of snow covered rosettes in January and February, but there was only ~ 5 cm in March (personal observation) and this may have allowed rosettes to engage in relatively higher levels of photosynthesis before and after the warming spells in March increasing energy cost and susceptibility to cold temperature stress. Snow cover was most likely not a significant impact factor since snow was not fully melted on top of the buckets by the end of the warming spell treatments and relatively similar amounts of snow were placed back on top of the rosettes after the warming spell treatments. The plants or seeds in both the large and small experimental containers expressed a similar response to the warming spell treatments. This result highlights how snow cover or heat capacity of each container likely had little influence on the effects of the warming spell in this experiment since snow cover and heat capacity of each container size were greatly different.

Table 5. Effect of simulated warming spell dates (WSD) in January, February, and March and seeding depth (cm) on seedling survival (% at bolting stage) and flowering date (first seed shed) for seedlings recruiting in the spring from Canada fleabane seeds (from southern Ontario populations) seeded outside at three sites in southern Ontario in the fall of 2009 and 2010

| WSD | Flowering date[z] | Survival[z] (%) 0.0 cm | Survival[z] (%) 0.5 cm |
|---|---|---|---|
| Control | 247*a* | 25.8*a* | 13.3*a* |
| Jan | 240*a* | 21.7*a* | 16.7*a* |
| Feb | 242*a* | 20.0*a* | 16.7*a* |
| March | 239*a* | 15.8*a* | 10.0*b* |

[z] Data pooled over years.

A Means within columns followed by different letters denote significant differences at P < 0.05.

The effect of warming spells on flowering timing may have been due to the triggering of Flowering Locus C (FLC) genes (Rudnoy et al. 2002). Canada fleabane has FLC genes that block flowering prior to vernalization removing any cold treatment requirement for floral initiation (Regeher and Bazzaz 1979). The results of this study suggest that plants (rosettes or overwintering seedlings) that are subjected to a disruption in vernalization take a significantly shorter time to flower. A cold period could silence the FLC genes, which are responsible for the suppression of flowering inducing hormones (He et al. 2004). Therefore, a vernalization period would promote the production of flowering inducing hormones (Wilczek et al. 2009). This could help to explain why we saw a gradient in flowering timings from latest to earliest for plants exposed to warming spells in January to March, respectively. In this regard, the warming spells reduced the suppression of flowering in all treatments, but March temperatures were potentially high enough after the warming spell for the plants to not return to a flowering suppression state, and plants exposed to March warming spells had the longest cold period with the highest temperatures after the warming spell. These conditions would have created the highest concentrations of flowering-inducing hormones and a period of high enough temperatures after the warming spell to prevent plants from re-entering a dormant (vernalization) state in relation to flowering. This combination of conditions would drive earlier flowering.

Warming spells did not have any significant effects (in terms of survival to bolting, flowering timing or fecundity) on seedlings emerging in the spring from seed set outside in the fall, or on the timing of recruitment of the seed. This suggests that any stress or triggering caused by the warming spells was effective on plants but not seeds.

This study indicated that there is significant variability in the over-winter survival of Canada fleabane and that the survival of Canada fleabane plants can potentially be very significantly affected by warming spells. We also showed that the timing and temperature of winter warming spells has a significant impact on level of survival and flowering timing, where the later the warming spell the greater the reduction in survival and the earlier the flowering timing. This could have significant effects on the population dynamics of Canada fleabane in a changing climate. Since a greater frequency of warming spells is predicted for this region (Shabbar and Bonsal 2003) in the future, this may encourage earlier flowering and seed shed, leading to greater proportional fall germination and also greater mortality for overwintering rosettes. This may also, however, select for spring emerging populations of Canada fleabane possibly making this weed a greater issue in spring- versus fall-seeded crops, and as such, perhaps a more common weed problem in spring-sown crops. Since in-laboratory germination rates were near 99% after 72 h (data not shown) the field results of this study support the notion that Canada fleabane seed has little or no dormancy and that the great majority of seed recruits (either in fall or spring) within a given season, as per other studies (Weaver et al. 2001). Seed burial encouraged greater overwintering seed persistence and germination in the spring, in particular for the late seeding date. Seeding depth had a significant effect on seedling survival ($P < 0.0292$) with greater seedling survival in seedlings established from seeds on the soil surface. This may have been related to time of emergence in the fall and size of seedlings, where emergence was more rapid for the surface-placed seed (personal observation) and those seedlings were perhaps more robust than later-emerging seedlings.

These results suggest that Canada fleabane seed does have an ability to remain viable over winter and that the later seed is shed in the fall the more likely that seed will germinate in the spring versus the fall. This supports the idea that seed shed timing (and to some extent shallow seed burial) plays a role in determining fall versus spring recruitment of Canada fleabane. As a result, limiting the number of plants setting seed would be an effective tactic for limiting Canada fleabane populations, which is good news for farmers managing Canada fleabane, especially herbicide resistant populations (VanGessel 2001).

## Conclusions

This study highlights the unique recruitment plasticity of facultative winter annual weeds and, for Canada fleabane, this plasticity involves a strong relationship between timing of seed shed and the extent to which this species recruits in the fall or spring. Understanding the recruitment biology and ecology of a facultative winter annual like Canada fleabane will help us to better manage this species and the results of this study represent a start to predicting how this species, and perhaps other facultative winter annuals with rosette morphologies (Lactuca serriola and Capsella bursapastoris), will perform as weeds in a changing climate.

## Acknowledgements

The authors thank the Natural Sciences and Engineering Research Council of Canada and The Ontario Ministry of Agriculture, Food and Rural Affairs for providing funding for this study and Robert Grohs, Rachel Riddle and Don Kitchen for technical assistance.

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