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# Fertilizer Application Has No Effect on Large (*Digitaria sanguinalis*) or Smooth (*Digitaria ischaemum*) Crabgrass Germination and Emergence in Residential Turfgrass in a Northern Climate

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Given the importance of emergence level and timing to the competitiveness and success of annual crabgrass species in turfgrass, particularly in the context of increasing synthetic pesticide bans and the common cultural practice of fertilization, a study was conducted in a northern region of North America (Ontario, Canada) to determine the effect of fertilizer application on large and smooth crabgrass emergence in residential lawns. In petri dish experiments, we reconfirmed that $KNO_3$ has a significant positive effect on large and smooth crabgrass seed germination but we showed that there is only an effect on fresh seed and no effect on aged seed, suggesting that the treatment affects dormancy level and not germination per se. In two other experiments using turf cores and commercial lawn fertilizer in growth room conditions and in field trials at three sites, we confirmed this result showing that neither fall nor spring fertilizer application had any effect on the emergence level of either smooth or large crabgrass. These results have practical relevance to homeowners and turf managers in this region because they are dealing with crabgrass emerging in the spring from seed shed the previous fall. The results also show that fertilizer can be used to aid turf quality and competitiveness without impacting true infestation level (density) of crabgrass in the spring.

**Nomenclature:** Large crabgrass, *Digitaria sanguinalis* (L.) Scop. DIGSA; smooth crabgrass, *Digitaria ischaemum* (Schreb.) Schreb. ex Muhl. DIGIS.

**Key words:** Cosmetic pesticide ban, potassium nitrate ($KNO_3$), weed recruitment.

Smooth and large crabgrass are two of the most common weeds to infest managed turfgrass (Hoyle et al. 2008; Melichar et al. 2008) and are serious competitors in turfgrass under both favorable (Wiese and Vandiver 1970) and stressed environments (such as heat and drought) (Danneberger and Code 1993; King and Oliver 1994; Wang et al. 2005). The competitiveness of crabgrass (both smooth and large) is attributed to its warm-season ($C_4$) character making it stress-tolerant to heat and drought (Long 1983), its rapid growth ability (Melichar et al. 2008), and its high fecundity (Aguyoh and Masiunas 2003; Johnson and Coble 1986; Melichar et al. 2008; Peters and Dunn 1971; Royer and Dickenson 1999), often allowing these species to dominate turfgrass swards. This is particularly true for poorly maintained or thin turf stands, which provide crabgrass greater opportunities for recruitment and establishment (Turner et al. 2012).

Fertilizer application is a common cultural practice within a healthy lawn management strategy. Previous studies that have focused on turf health have reported a reduction in late-season crabgrass cover with fertilizer applications in Kentucky bluegrass (*Poa pratensis* L.) (Dunn et al. 1981 as cited in Busey 2003; Johnson 1981; Johnson and Bowyer 1982; Murray et al. 1983), tall fescue (*Lolium arundinaceum* S.J. Darbyshire) (Dernoeden et al. 1993; Voigt et al. 2001), and red fescue swards (*Festuca rubra* L.) (Jagschitz and Ebdon 1985). However, in terms of impacts on weed management, results of these studies have been inconsistent between years and have varied depending on experimental conditions where, for example, fertilizer application combined with a low mowing height generally did not reduce crabgrass infestation levels. Typical lawn care recommendations call for fertilizer applications only when there is minimal weed growth to avoid greater competition (Busey 2003; Cudney and Elmore 2000) and as such, fertilizer is often applied before crabgrass seed germinates in the spring, or when crabgrass seed is dormant in the fall.

Nitrogenous compounds have been shown to reduce seed dormancy levels and enhance germination for seeds of some weed species, including crabgrass. Intact spikelets of large crabgrass treated with $KNO_3$ 2 mo after harvest resulted in 12% germination compared to only 4% in water controls after a 15-d period (20/30 C in 12/12 h of light/

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dark, respectively) (Gallart et al. 2008). $KNO_3$ (applied at 0.25%) has also been shown to break seed dormancy in large crabgrass seed (Delouche 1956) with greater effect when the seed is hulled (Delouche 1956; Gallart et al. 2008). In other experimentation with $KNO_3$, effects on dormancy levels for fresh large crabgrass seed have been inconsistent (Toole and Toole 1941). For fresh smooth crabgrass seed considered to be dormant, $KNO_3$ (applied at 0.2%) has been found to promote the rate of germination of at temperature regimes of 15/25 C and 20/30 C but retard germination rate at higher temperature regimes of 20/35 C or 20/40 C (18/6 h) (Toole and Toole 1941). These results suggest that fertilizer applications may impact crabgrass recruitment and establishment, but this has never been tested.

Given the importance of emergence level and timing to the competitiveness and success of annual crabgrass species in turfgrass, particularly in the context of increasing synthetic pesticide bans and the common cultural practice of fertilization, a study was conducted in a northern region of North America (Ontario, Canada) to determine the effect of fertilizer application on large and smooth crabgrass emergence in residential lawns. Unique from previous studies, the current study also considered the impact of seed age. The context of this study is northern North America, where there is a substantive winter season, which defines lawn management timing, including fertilizer application timing, and which impacts crabgrass seed dormancy. Within this region, after seed is shed in late summer and early fall, seed of both large (Delouche 1956, Gianfagna and Pridham 1951; Toole and Toole 1941) and smooth (Baskin and Baskin 1988; Toole and Toole 1941) crabgrass is immature and considered dormant, requiring a period of after-ripening. It may take approximately 4 to 6 mo for crabgrass to reach complete maturity and germinability (Gallart et al. 2008; Gianfagna and Pridham 1951; Masin et al. 2006; Peters and Dunn 1971; Taylorson and Brown 1977; Toole and Toole 1941). Conducting experiments on both freshly harvested and aged seed would mimic the seed states during fall and spring fertilizer application periods, respectively. In this study we also intended to carry the experiments from petri dish to field scale in order to determine whether lab results translated to real weed emergence conditions in turfgrass and we conducted a series of three experiments to achieve this. We hypothesized that fertilization of both fresh and aged large and smooth crabgrass seed (considered to be dormant and nondormant, respectively) would increase their overall germination and emergence compared to the control in each of our three experiments.

## Materials and Methods

**Seed Collection.** Seedlings of large crabgrass were collected from mixed grass swards in Simcoe, Guelph, and Burlington, ON, Canada on June 15, July 5, and July 23, 2010, and seedlings of smooth crabgrass were collected on June 15, July 12, and July 23, 2010. Seedlings were transplanted into pots kept outdoors and watered regularly. Once ripened, seed of large crabgrass was collected from early August to mid-September and seed of smooth crabgrass was collected from late August to late September, approximately weekly, and stored in paper bags. Sheltered from rain and allowed to dry, collected seed was exposed to outdoor temperatures up until the time of use in the first experiments (fresh seed).

**In Vitro Testing of the Effect of $KNO_3$ on Crabgrass Seed Germination.** Experiments were conducted using freshly harvested seed and aged seed, which approximated dormant and nondormant seed, respectively. Two separate runs of the experiment with fresh seed of large and smooth crabgrass began on October 25, 2010, and November 1, 2010, and were concluded on January 10, 2010. Seed not used in the first experiment (the fresh seed experiment) was stored in dark, dry conditions at 5 C in paper bags (for the length of the winter season, approximately 5 mo) until the second experiment (the aged seed experiment). Two separate runs of the aged seed experiment using seed of large and smooth crabgrass began on April 29, 2011, and May 2, 2011, and were concluded on May 24, 2011, and May 28, 2011, respectively.

For each experiment, sound seed (full, normal coloration, intact hull) was selected and counted into samples of 100 and placed into 9-mm petri dishes. Seed was rinsed with 5% NaOCl for 10 min and completely rinsed with deionized water five times for surface sterilization (ISTA 1985). For each experiment for each species, treatments were arranged as a randomized complete block design with five replications and two treatments ($KNO_3$ or $H_2O$) and each experiment was conducted twice (two runs) for validation (Figure 1). Treatments were either 3 ml 0.2% $KNO_3$ or 3 ml deionized $H_2O$ as per Gallart et al. (2008) and Toole and Toole (1941). Growth chamber conditions were



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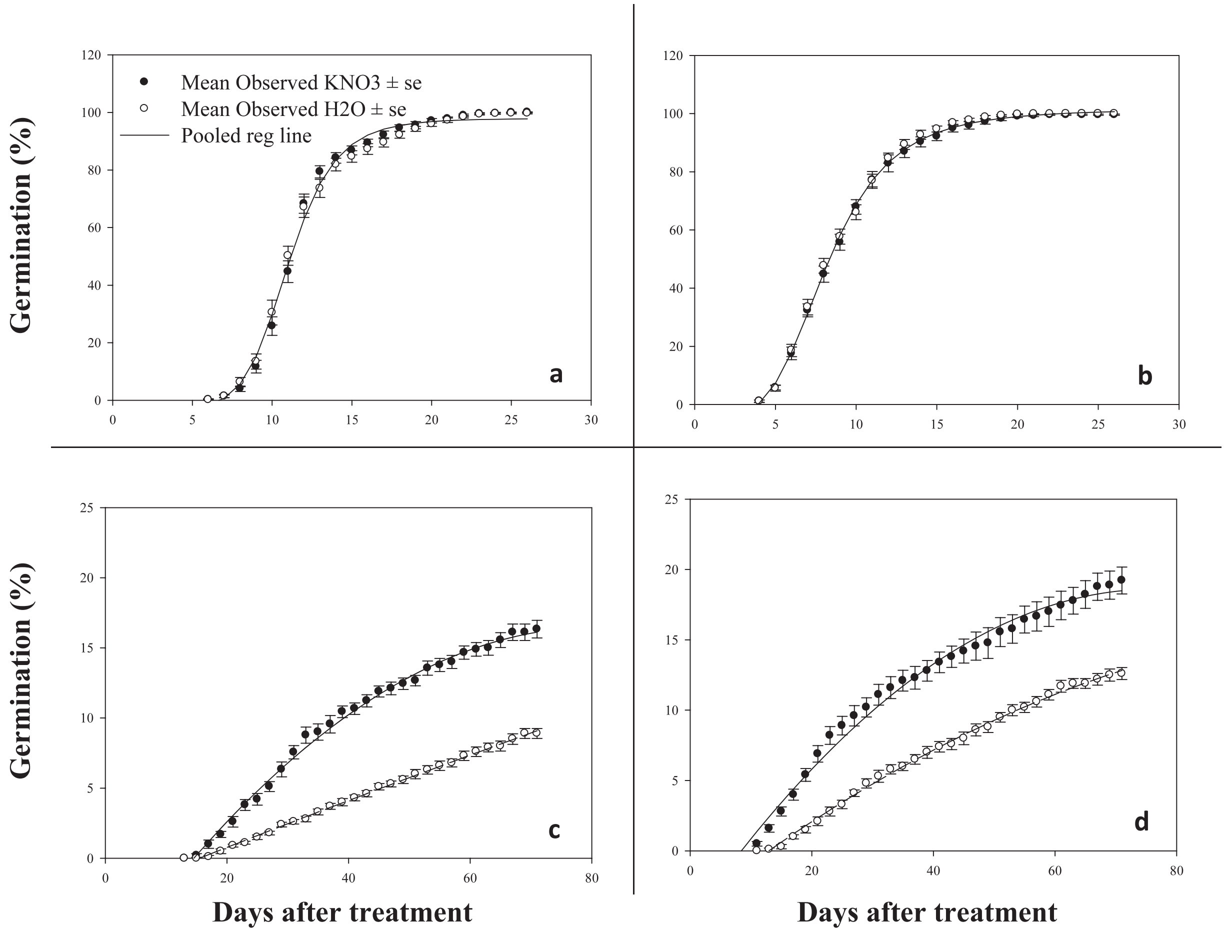


Figure 1. Mean germination of (a) fresh smooth and (b) large and (c) aged smooth and (d) large crabgrass seed after treatment with 0.2% $KNO_3$ solution or an $H_2O$ control. (a, b) Germination is not significantly different between treatments ($P > 0.05$). Markers represent mean values for each assessment date, and lines represent the fitted logistic regression equation ($y = C + D/[1+ \{x/E_{50}\}^b]$). Refer to Table 3 for parameter estimates and to the Materials and Methods section for a description of the model. (c, d) Germination is significantly different between treatments after day 19 ($P \leq 0.05$). Markers represent mean values for each assessment date, and lines represent the fitted quadratic regression equation ($y = ax^2 + bx + c$). Refer to Table 2 for parameter estimates of and to the Materials and Methods section for a description of the model.

regulated in 12-h light cycles at temperatures of 20/30 C. Seed was monitored daily and water was added as necessary to maintain imbibition. Germination was recorded with the first appearance of the radicle and once counted, germinated seeds were removed. Seed viability was determined using an imbibed crush test (ISTA 1985) on seed immediately prior to commencing the $KNO_3$ and $H_2O$ treatments of fresh and aged crabgrass, and at the end of experiments on seeds that had not germinated (Table 1). Seed that collapsed under pressure was considered nonviable. Percentage of viability was calculated using the following equation:

$$\%\mathrm{Seed}_{\mathrm{viable}} = \left(\left[\mathrm{Seed}_{\mathrm{germinated}} + \mathrm{Seed}_{\mathrm{uncrushed}}/\mathrm{Seed}_{\mathrm{total}}\right] \times 100\right) \quad [1]$$

Statistical analysis was conducted using the SAS® System, Windows Platform (Version 9.2, SAS Institute, Cary, NC). Analysis of variance was performed using the general linear model procedure to test for significance of treatment effects, experimental factors, and interactions. For all data sets, data were found to be normally distributed. Run was never significant and all data was pooled over run. For the fresh seed experiments and for both species, treatment and time were significant factors and so we proceeded with regression analysis separately for each treatment. For experiments using aged seed, treatment was not a significant factor but time was significant and we proceeded with regression analysis combined over treatments.

Means of the cumulative germination were calculated for each treatment using PROC MEANS in SAS and were used to run nonlinear regression. After inspecting the shape of the plotted curve using observed data, a quadratic equation was fitted for experiments using fresh seed of large and smooth



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Table 1. Mean percentage of viability of smooth and large crabgrass before and after experimentation with fresh and aged seed.

| Treatment[a] | Mean %[b] | Standard error |
|---|---|---|
| Fresh smooth seed | | |
| Original | 100.0 a | 0.00 |
| $H_2O$ | 88.6 b | 1.33 |
| $KNO_3$[c] | 84.9 c | 1.55 |
| Aged smooth seed | | |
| Original | 99.7 a | 0.21 |
| $H_2O$ | 99.8 a | 0.20 |
| $KNO_3$ | 100.0 a | 0.00 |
| Fresh large seed | | |
| Original | 99.9 a | 0.10 |
| $H_2O$ | 87.9 b | 1.57 |
| $KNO_3$ | 84.8 c | 2.31 |
| Aged large seed | | |
| Original | 99.6 a | 0.22 |
| $H_2O$ | 100.0 a | 0.00 |
| $KNO_3$ | 99.6 a | 0.22 |

[a] Original denotes seed tested prior to experiments. $H_2O$ and $KNO_3$ denotes seed tested after experiments within the respective treatment.

[b] Means followed by the same letter in a column are not significantly different within species ($p > 0.05$) according to Fisher's Protected LSD.

[c] 0.2% $KNO_3$ solution used.

crabgrass. The coefficients of the regression equation and standard errors were calculated using nonlinear regression (PROC NLIN) (Tables 2 and 3). The equation of the quadratic model fitted was as follows:

$$y = ax^2 + bx + c \quad [2]$$

where $y$ is cumulative percentage of emergence of crabgrass, $x$ is the day after treatment (time), a is the quadratic slope parameter, b is the linear slop parameter, and c is the intercept. For experiments using aged seed of large and smooth crabgrass, a logistic equation was fit to satisfy the data's obvious sigmoidal trend (De Corby et al. 2007) (Table 3). The equation of the logistic model fitted was

$$y = C + D \Big/ \left(1 + [x/E_{50}]^b\right) \quad [3]$$

where $y$ is cumulative percentage emergence of crabgrass, $x$ is the day after treatment (time), $C$ is the lower limit (asymptote) of the response curve, $C + D$ is the upper asymptote (maximum emergence), $E_{50}$ is the $x$ value (day) at the midpoint or the inflection point of the curve (not necessarily the day at 50% emergence depending upon the values of the fitted $C$ and $D$ parameter estimates and the shape of the curve), and $b$ is the slope (Burke et al. 2005; Seefeldt et al. 1995).

The viability of fresh and aged seed pre- and postexperimentation was analyzed using PROC MIXED in SAS with fixed treatment effects and random block effects (Table 1). A multiple means comparison was conducted for each analysis with the assistance of a "pdmix800" macro (Saxton 1998), which generates letter values according to significant differences of the least squared means relevant to one another.

**Testing the Effect of Fertilizer Application on Crabgrass Recruitment in Turf under Controlled Conditions.** In the second set of experiments in this study we wanted to test whether the results from the petri dish experiments translated to crabgrass recruitment within turfgrass swards growing in soil. We conducted these experiments under the same controlled (growth chamber) conditions as our first experiment. For each species, experiments were arranged as a randomized complete block design with four replications and five fertilizer treatments split by two turf types (sites) and each experiment was conducted twice (two runs) for validation. Fertilizer used for treatments was a commercially available 32–0–10 product (Scott's Turf Builder Pro™, Scotts Miracle-Gro Company Canada Ltd. Mississauga, ON, Canada), which has a recommended rate of 155 kg $ha^{-1}$ and translates to

Table 2. Parameter estimates (standard errors in parentheses) for the germination of fresh smooth and large crabgrass seed treated with 0.2% $KNO_3$ solution or an $H_2O$ control. Percentage of crabgrass germination was expressed as a function of days after treatment and a quadratic model was fitted ($y = ax^2 + bx + c$ ).

| Treatment[a] | a | b | c | $R^2$ |
|---|---|---|---|---|
| Smooth crabgrass | | | | |
| $KNO_3$ | −8.0 (0.32) | 0.6 (0.02) | −0.004 (0.0002) | 0.99 |
| $H_2O$ | −2.7 (0.32) | 0.2 (0.02) | −0.0001 (0.0002) | |
| Large crabgrass | | | | |
| $KNO_3$ | −4.9 (0.44) | 0.6 (0.02) | 0.004 (0.0003) | 0.99 |
| $H_2O$ | −4.1 (0.44) | 0.3 (0.02) | −0.0014 (0.0003) | |

[a] Treatments are significant ($P \leq 0.05$).



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Table 3. Parameter estimates (standard errors in parentheses) for the germination of aged smooth and large crabgrass seed treated with 0.2% $KNO_3$ solution or an $H_2O$ control. Percentage of crabgrass germination was expressed as a function of days after treatment and a logistic model was fitted ($y = C + D/[1 + \{x/E_{50}\}^b]$).

| Pooled treatments[a] | C | D | $E_{50}$ | b | $R^2$ |
|---|---|---|---|---|---|
| | | | DAT | | |
| Smooth crabgrass | −2.4 (1.47) | 100.3 (1.76) | 11.05 (0.08) | −7.6 (0.37) | 0.99 |
| Large crabgrass | −4.5 (1.07) | 106.1 (1.28) | 8.2 (0.06) | −4.2 (0.10) | 0.99 |

[a] $KNO_3$ and $H_2O$ treatments are not significant ($P > 0.05$).

46.5 kg available N $ha^{-1}$ and 15.5 kg $K_2O$ $ha^{-1}$. Nitrogen was available as water-soluble urea. Treatments were chosen relative to the recommended rate including 0× (control), 1× (recommended rate), 2×, 4×, and 8×. Fertilizer prills were ground to a powder using a ceramic mortar and pestle to facilitate even distribution over the small sward cores.

Turf cores were taken from two distinct sites to account for potential site and soil differences using a 10-cm golf course cup cutter on October 14, 2010, and May 4, 2011, for experiments using fresh and aged seed, respectively. Turf from the site near Guelph, ON, Canada (Guelph) consisted of a mix of perennial ryegrass (*Lolium perenne* L.), Kentucky bluegrass, and fine fescues (*Festuca* spp.), whereas turf from the Simcoe, ON, Canada site (Simcoe) also had some creeping bentgrass (*Agrostis stolonifera* L.). Cores were cut to a 7-cm depth and potted into individual plastic 10-cm diam pots. Turf within the pots was cut regularly throughout the experiments to a 6.25-cm height to simulate mowing. At trial initiation, crabgrass seed (100 sound seeds $pot^{-1}$) was distributed evenly over each core and the same was done with required fertilizer treatments, after which all pots were watered. Growth chamber conditions were set as per the petri dish experiments. Turf cores were watered regularly throughout the experiments as required to maintain surface moisture for imbibition and healthy turf. Recruited crabgrass seedlings were counted twice per week and were removed once counted. For the fresh seed experiments, turf was sprayed once with pymetrozine (Endeavor 50WG™ WG, Syngenta Crop Protection Canada Inc., Guelph, ON, Canada) at a rate of 0.1 g ai $L^{-1}$ until leaf soak on November 28, 2011, to eradicate pest aphids.

Statistical analysis of data was performed using SAS® System, Windows Platform (Version 9.2, SAS Institute). Analysis of variance was performed using the general linear model procedure to test the significance of treatment effects, experimental factors, and interactions. For all data sets, data were found to be normally distributed. Run was never significant and all data were pooled over run. For the fresh seed experiments, fertilizer treatments and day after treatment (time) were significant factors. In addition, for the fresh seed large crabgrass experiment, turf type was a significant factor. We proceeded with regression analysis separately for fertilizer treatments and for large crabgrass we also separated by turf type (Table 4). For the experiments using aged seed, only days after treatment (time) was a significant factor. For the aged seed experiments we proceeded with a regression analysis combined over all factors.

The means of cumulative emergence were used to run nonlinear regressions and again, a quadratic (Equation 2) and logistic (Equation 3) equation was fitted for experiments using fresh and aged seed, respectively, as described for analysis of the petri dish experiments (Tables 4 and 5).

**Testing the Effects of Fall or Spring Fertilizer Application on Crabgrass Recruitment in Turfgrass.** In the final experiment of this study, our objective was to determine whether the results from the controlled condition studies translated to crabgrass recruitment in turfgrass swards outdoors. Field sites were established at three locations in southern Ontario in the summer of 2010. Sites were selected based on two key criteria: (1) The site could not have any natural populations of large or smooth crabgrass (as determined by previous observation) and (2) the turfgrass must be generally typical of an average residential mixed grass sward (the stand should be moderately dense and appear healthy). Sites were located in Guelph, Woodstock, and Simcoe, ON, Canada. For all sites, turf was a mix of species to represent the average residential lawn. This consisted of perennial ryegrass, Kentucky bluegrass, and fine fescues at both sites, with the addition of some creeping bentgrass at the Simcoe site. Soil texture was classified as loam at the Guelph and Woodstock sites whereas Simcoe was a very fine sandy loam (Table 6). Bulk density and pH ranged from 1.42 to 1.47 g $cm^{-3}$ and 7.4 to 7.6, respectively, and the nutrient profiles had some



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Table 4. Parameter estimates (standard errors in parentheses) for the emergence of fresh smooth and large crabgrass seed after five fertilizer treatments within a model turfgrass environment. Percentage of crabgrass emergence was expressed as a function of days after treatment (DAT) and a quadratic model was fitted ($y = ax^2 + bx + c$).

| Treatment[a,b] | a | b | c | $R^2$ |
|---|---|---|---|---|
| Smooth crabgrass | | | | |
| 0× | −1.0 (0.40) | 0.1 (0.01) | $1.5 \times 10^{-4}$ ($9.9 \times 10^{-5}$) | 0.99 |
| 1× | −1.5 (0.40) | 0.1 (0.01) | $-4.0 \times 10^{-5}$ ($9.9 \times 10^{-5}$) | |
| 2× | −2.74 (0.40) | 0.2 (0.01) | $-5.6 \times 10^{-4}$ ($9.9 \times 10^{-5}$) | |
| 4× | −3.8 (0.40) | 0.3 (0.01) | $-1.2 \times 10^{-3}$ ($9.9 \times 10^{-5}$) | |
| 8× | −5.8 (0.40) | 0.4 (0.01) | $-1.8 \times 10^{-3}$ ($9.9 \times 10^{-5}$) | |
| Large crabgrass (Guelph) | | | | |
| 0× | −2.9 (0.41) | 0.2 (0.2) | $-5.0 \times 10^{-5}$ ($1.2 \times 10^{-4}$) | 0.99 |
| 1× | −5.8 (0.41) | 0.4 (0.2) | $-1.4 \times 10^{-3}$ ($1.2 \times 10^{-4}$) | |
| 2× | −5.2 (0.41) | 0.5 (0.2) | $-1.9 \times 10^{-3}$ ($1.2 \times 10^{-4}$) | |
| 4× | −3.8 (0.41) | 0.5 (0.2) | $-2.1 \times 10^{-3}$ ($1.2 \times 10^{-4}$) | |
| 8× | −4.3 (0.41) | 0.6 (0.2) | $-2.3 \times 10^{-3}$ ($1.2 \times 10^{-4}$) | |
| Large crabgrass (Simcoe) | | | | |
| 0× | −2.9 (0.41) | 0.1 (0.02) | $6.6 \times 10^{-4}$ ($1.2 \times 10^{-4}$) | 0.99 |
| 1× | −5.8 (0.41) | 0.1 (0.02) | $1.2 \times 10^{-4}$ ($1.2 \times 10^{-4}$) | |
| 2× | −5.2 (0.41) | 0.2 (0.02) | $-1.6 \times 10^{-4}$ ($1.2 \times 10^{-4}$) | |
| 4× | −3.8 (0.41) | 0.3 (0.02) | $-6.2 \times 10^{-4}$ ($1.2 \times 10^{-4}$) | |
| 8× | −4.3 (0.41) | 0.5 (0.02) | $-2.0 \times 10^{-3}$ ($1.2 \times 10^{-4}$) | |

[a] Treatments are significant ($P \leq 0.05$).
[b] 1× represents the recommended rate of 155 kg $ha^{-1}$ for a 32–0–10 product (Scott's Turf Builder Pro™, Scotts Miracle-Gro Company Canada Ltd. Mississauga, ON, Canada).

variability (Turner 2012). Prior to crabgrass seed distribution, all sites were treated with 550 g ai $ha^{-1}$ mecoprop D-isomer, 1,045 g ai $ha^{-1}$ 2,4-D isomer-specific, and 99 g ai $ha^{-1}$ dicamba (Par III™, United Agri Products Canada Inc., Dorchester, ON, Canada) (broadleaf herbicides) to help reduce potential variation in stand vegetation within and among sites (see Table 7 for application dates). In addition, at the time of seed distribution, any broadleaf weeds remaining were removed by hand. Turfgrass was mowed weekly at each site to maintain a typical lawn height of approximately 6.5 cm. Turfgrass was evaluated at three times in the year (June 20, July 25, and August 22, 2011) for density and quality using a rating scale of 1 to 9 according to the guidelines of the National Turfgrass Evaluation Program (Morris and Shearman 2008).

At each site, soil temperatures were recorded continuously throughout the observation period using two randomly placed temperature data loggers (Hobo Pro v2 U23-004, Onset Computer Corporation, Bourne, MA) buried approximately 1 cm beneath the soil surface. The two data sets were averaged for each site before calculating cumulative soil growing degree days (GDD). Daily GDD measurements were calculated from January 1, 2011, until the end of the study. The following equation was used to calculate GDD:

$$GDD_{daily} = (T_{max} + T_{min})/2 - T_{base} \qquad [4]$$

where $T_{max}$ is the maximum daily soil temperature, $T_{min}$ is the minimum daily soil temperature, $T_{base}$ is the base temperature at which plant growth and development was deemed not to occur (10 C in this study). When $T_{min} < T_{base}$, its value was replaced by 10 and individual daily GDD values were summed to provide a cumulative daily GDD value.

Table 5. Parameter estimates (standard errors in parentheses) for the emergence of aged smooth crabgrass seed after five fertilizer treatments within a model turfgrass environment. Percent crabgrass germination was expressed as a function of days after treatment (DAT) and a logistic model was fitted ($y = C + D/[1 + \{x/E_{50}\}^b]$).

| Pooled treatments[a] | C | D | $E_{50}$ | b | $R^2$ |
|---|---|---|---|---|---|
| | | | DAT | | |
| Smooth crabgrass | 0.7 (0.50) | 100.2 (0.59) | 11.2 (0.03) | −6.3 (0.09) | 0.99 |
| Large crabgrass | −1.9 (0.50) | 102.7 (0.60) | 11.8 (0.04) | −6.6 (1.00) | 0.99 |

[a] Fertilizer treatments are not significant ($P > 0.05$).



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Table 6. Soil particle size distribution and nutrient profile of large and smooth crabgrass field sites.[a]

| | Site | | |
|---|---|---|---|
| | Guelph | Simcoe | Woodstock |
| | % | | |
| Soil texture[b] | | | |
| Gravel | 0.9 | 0.6 | 2.8 |
| Sand | 49.2 | 52.5 | 49.1 |
| Very fine sand | 20.7 | 21 | 12.2 |
| Fine sand | 19.2 | 19.1 | 16.3 |
| Medium sand | 5.7 | 9.2 | 11.3 |
| Coarse sand | 2.4 | 2.3 | 6.4 |
| Very coarse sand | 1 | 0.1 | 2.5 |
| Silt | 37.2 | 40.4 | 37.2 |
| Clay | 13.6 | 7.1 | 13.7 |
| Texture | Loam | Very fine sandy loam | Loam |
| Bulk density (g $m^{-3}$) | 1.42 | 1.47 | 1.46 |
| Nutrient profile | | | |
| Soil moisture (%) | 24.1 | 36.38 | 25.06 |
| Ammonium-N (mg $kg^{-1}$ dry) | 4.28 | 9.1 | 5.68 |
| Nitrate-N (mg $kg^{-1}$ dry) | 4.88 | 5.92 | 11.3 |
| Extractable P (mg $L^{-1}$ dry) | 44 | 44 | 67 |
| Extractable Mg (mg $L^{-1}$ dry) | 400 | 180 | 160 |
| Extractable K (mg $L^{-1}$ dry) | 78 | 41 | 160 |
| Organic matter (% dry) | 3.9 | 5.5 | 5 |
| pH | 7.6 | 7.6 | 7.4 |

[a] Organic matter determined by the Walkley-Black method.
[b] Samples collected May 9, 2011.

This experiment was designed as a randomized complete block design, split by species with three replicates per treatment and the statistical analysis was conducted for each species separately. Individual subplots were 25 by 50 cm. There were five fertilizer treatments: 1× (recommended rate) fall fertilizer, 1× spring fertilizer, 8× fall fertilizer, 8× spring fertilizer, and no fertilizer. The same fertilizer product was used as described for the growth chamber experiment. The 8× treatments were not representative of common homeowner practice but were included to rigorously test for possible effects. The 8× fertilizer rate would be equivalent to 372 kg available N $ha^{-1}$ and 124 kg $K_2O$ $ha^{-1}$.

In the fall of 2010, approximately 1,000 crabgrass seeds were applied per subplot. Application dates followed the last date of seed collection for the given species (Table 7) and consequently, because large crabgrass matured earlier in the fall than did smooth crabgrass, it was applied earlier. Seed was distributed evenly using a standard parmesan cheese shaker, and seed was mixed with Therm-O-Rock™ vermiculite and perlite to provide bulk and to facilitate spreading. The fall

Table 7. Large and smooth crabgrass field study seed distribution and treatment timing.

| | | Treatment | | | | |
|---|---|---|---|---|---|---|
| Species | Site | Treated with Par III[a] | Seed distribution[b] | Raking | Fall fertilization | Spring fertilization |
| Large crabgrass | Woodstock | August 19, 2010 | September 22, 2010 | September 22, 2010 | October 19, 2010 | May 31, 2011 |
| | Simcoe | August 30, 2010 | September 23, 2010 | September 23, 2010 | October 18, 2010 | May 31, 2011 |
| | Guelph | September 8, 2010 | September 24, 2010 | September 24, 2010 | October 17, 2010 | May 31, 2011 |
| Smooth crabgrass | Woodstock | August 19, 2010 | October 19, 2010 | October 19, 2010 | October 19, 2010 | May 31, 2011 |
| | Simcoe | August 30, 2010 | October 18, 2010 | October 18, 2010 | October 18, 2010 | May 31, 2011 |
| | Guelph | September 8, 2010 | October 17, 2010 | October 17, 2010 | October 17, 2010 | May 31, 2011 |

[a] 2,4-D, mecoprop, and dicamba.
[b] Large crabgrass and smooth crabgrass seed distribution for 8× fall and spring fertilizer treatments occurred on the same date as all other smooth crabgrass seeding.



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Table 8. Parameter estimates (standard errors in parentheses) for emergence timing of large and smooth crabgrass (Figure 3) at three site-years in southern Ontario. Percentage of crabgrass emergence was expressed as a function of cumulative soil growing degree days (GDD) and a logistic model was fitted ($y = C + D/[1 + \{x/E_{50}\}^{b}]$).

| Site | C | D | $E_{50}$ | b | $R^2$ |
|---|---|---|---|---|---|
| | % | % | GDD | | |
| Large crabgrass | | | | | |
| Guelph | −5.4 (2.66) | 121.9 (6.87) | 775.5 (20.70) | −3.1 (0.30) | 0.99 |
| Simcoe | −8.2 (3.49) | 123.8 (7.64) | 780.8 (20.86) | −3.0 (0.29) | |
| Woodstock | −7.9 (3.30) | 121.1 (6.71) | 766.2 (19.72) | −2.9 (0.28) | |
| Smooth crabgrass | | | | | |
| Guelph | −4.6 (2.01) | 108.4 (3.00) | 468.4 (8.52) | −3.1 (0.18) | 0.99 |
| Simcoe | −5.0 (2.56) | 108.9 (3.46) | 522.0 (10.10) | −3.4 (0.22) | |
| Woodstock | −3.1 (1.70) | 103.7 (2.22) | 458.8 (7.48) | −3.5 (0.19) | |

fertilizer treatments were applied only after all the seed (for both species) was applied. Control plots that were not meant to have any seed applied still received an application of vermiculite and perlite mix.

After the seed was distributed, weekly emergence observations were made in the fall of 2010 until first frost and resumed in April of 2011 until mid-September, 2011. Turf was thoroughly parted to observe newly germinated crabgrass and seedlings were removed as they were counted. Field observations ended when emergence in all subplots slowed to an emergence level of two or fewer seedlings per week for two consecutive weeks. In the final week of observations, there was no crabgrass emergence in any plots.

Analysis of variance was performed on the data using the general linear model procedure to test for treatment effects, the significance of experimental factors and interactions. For both large and smooth crabgrass, site and week (time) were significant but fertilizer treatment was not and neither was run. Data were pooled over run and for both species we proceeded with regression analysis separately for each site. The means of cumulative percentage of emergence were used to run nonlinear regressions and a logistic equation (Equation 3) was fitted for each site for large and smooth crabgrass (Table 8).

A three-parameter equation was fitted for Julian date (JDate) and the coefficients of the regression equation and standard errors were calculated using nonlinear regression (PROC NLIN) as a function of cumulative soil GDD. The model fitted was (Ratkowsky 1990)

$$GDD = A + \left(B \times JDate^{C}\right) \qquad [5]$$

where A is the intercept and B and C are parameters that determine the shape of the curve. The resulting best fit equation is appropriate for use only within the range of experimental Julian dates. The resulting equation was used to determine the correct Julian date for a given GDD.

## Results and Discussion

**In Vitro Testing of Effect of Potassium Nitrate on Crabgrass Seed Germination.** Aged seed of smooth (Figure 1a) and large crabgrass (Figure 1b) reached 100% germination within 30 d after the start of the experiments and there was no difference in germination level or rate whether or not $KNO_3$ was applied. However, when fresh seed was used the overall final germination levels were much lower (19% at most) and there was significantly more germination of both smooth (Figure 1c) and large crabgrass seed (Figure 1d) when $KNO_3$ was applied. For smooth crabgrass, germination increased from 9 to 16% and for large crabgrass, it increased from 13 to 19%. These results suggest that fresh crabgrass seed is largely dormant and that $KNO_3$ can act to release dormancy in a portion of fresh seeds. The aged seed germinated very quickly in comparison. Final germination levels were achieved in the aged seed experiments in less than half the time of the fresh seed experiments (30 d vs. 71 d, respectively). Viability of fresh and aged seed prior to experimentation was not significantly different for either species. There was a significant reduction in seed viability for experiments using fresh seed but not for those using aged seed (Table 2). This was presumably due to the difference in duration of the aged vs. the fresh seed experiments where the fresh seed was exposed to moist conditions for a much longer time, and there was an even greater reduction in viability when $KNO_3$ was applied, which may be the result of enhanced microbial growth (Turner, unpublished data) resulting from the enriched nutrient conditions.

The results of these in vitro germination experiments are similar to those of previous studies (Baskin and Baskin 1988; Delouche 1956; Gallart et al. 2008; Gianfagna and Pridham 1951; Masin et al. 2006; Peters and Dunn 1971; Taylorson and



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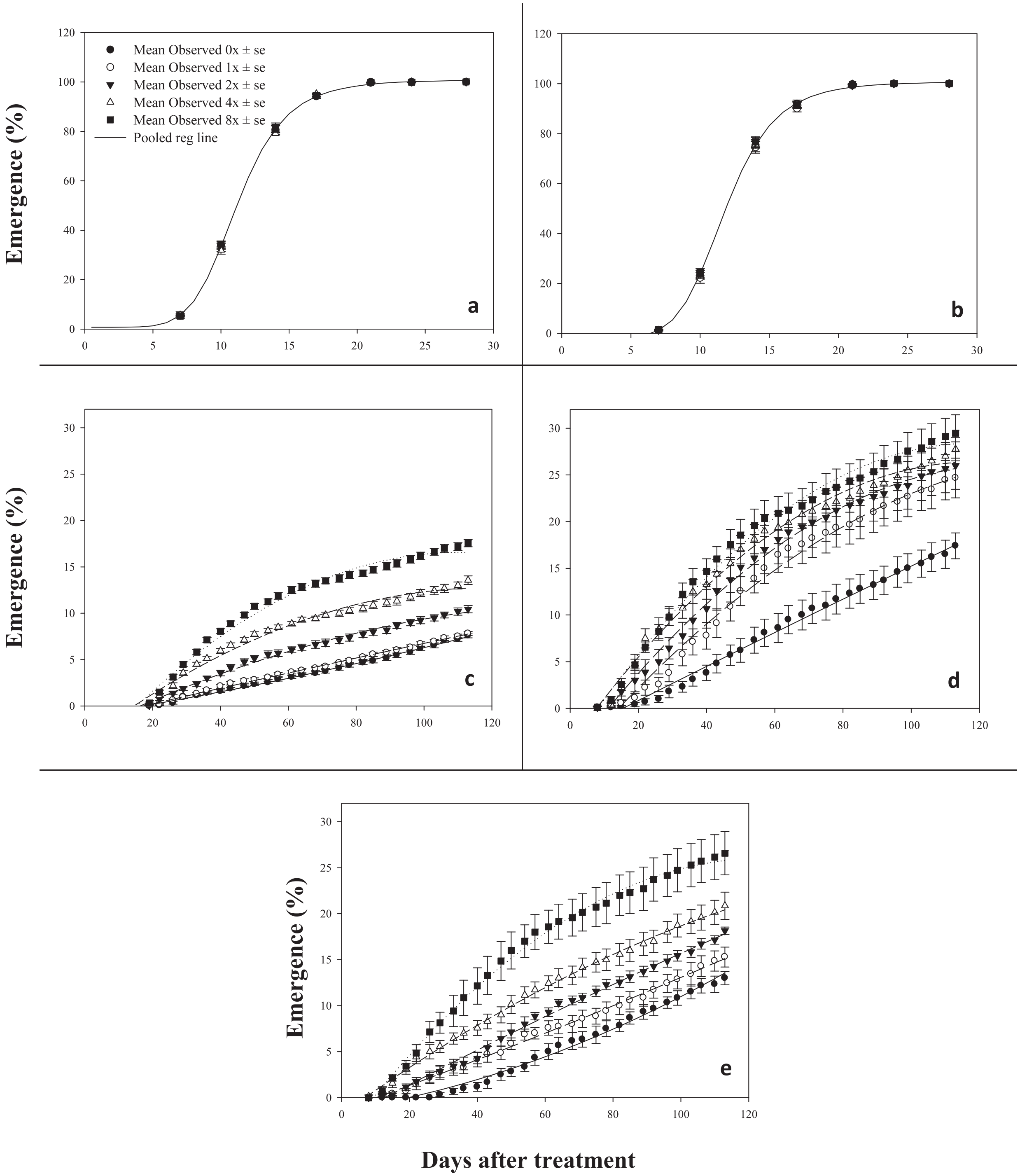


Figure 2. Mean germination of (a) aged smooth and (b) large and (c) fresh smooth and large ([d] Guelph, [e] Simcoe) crabgrass seed after treatment with five fertilizer rates in a model turfgrass environment. Emergence of (a, b) aged seed is not significantly different between treatments ($P > 0.05$). Emergence of (c, d, e) fresh seed is significantly different between treatments ($P \leq 0.05$). Markers represent mean values for each assessment date, and lines represent the fitted logistic ($y = C + D/(1 + [x/E_{50}]^b)$ and quadratic ($y = ax^2 + bx + c$) regression equations for aged and fresh seed, respectively. Refer to Tables 4 and 5 for parameter estimates for fresh and smooth seed, respectively, and to the Materials and Methods section for a description of the models.

Brown 1977; Toole and Toole 1941) and confirm that seed aging (even 8 mo of aging in the dark at 5 C) can break dormancy in crabgrass seed, and that $KNO_3$ can also break dormancy in a portion of fresh crabgrass seed.

**Fertilization in a Model Turfgrass System.** As per the results for the in vitro experiments, aged seed of both crabgrass species, reached 100% emergence quickly (within 30 d) (Figure 2). However, average emergence of fresh seed ranged from only 8 to 18%



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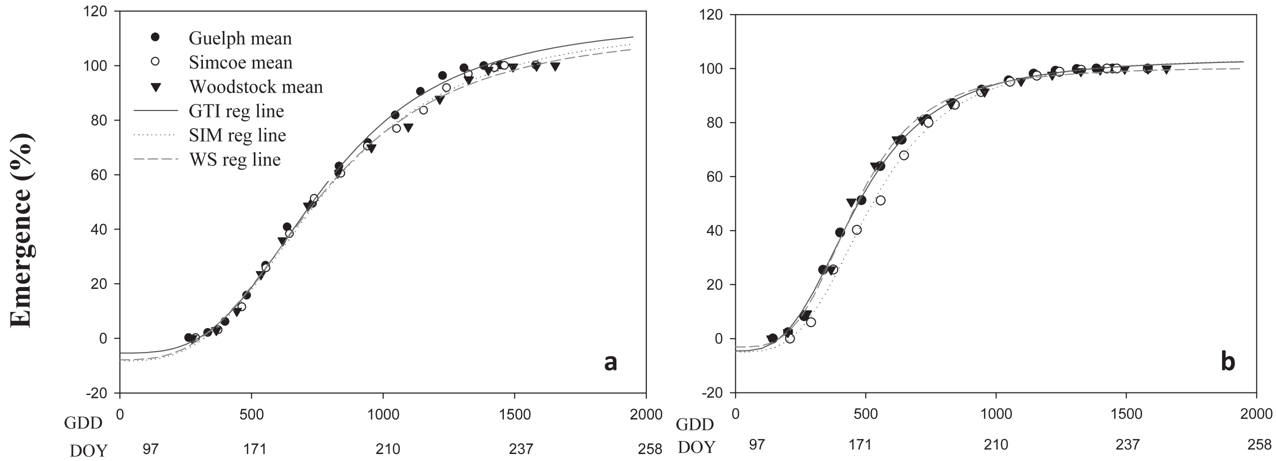


Figure 3. Emergence timing of (a) large and (b) small crabgrass across three site-years in southern Ontario as related to cumulative soil growing degree days (GDD). Base temperature at which plant growth and development was deemed not to occur was 10 C. Emergence is pooled across treatments (NS) and site is significant ($P \leq 0.05$). Markers represent mean values for each assessment date, and lines represent the fitted logistic regression equation ($y = C + D/(1+ [x/E_{50}]^b)$). Refer to Table 7 for parameter estimates and to the Materials and Methods section for a description of the model. Corresponding days of the year (DOY) are indicated in the second x-axis. The initial DOY value corresponds to 50 GDD. DOY 100 corresponded to April 10. Because sites were geographically close, temperature did not differ greatly between sites (data not shown); hence, DOY was averaged over sites when determining values for the second x-axis.

for smooth crabgrass and 12 to 26% for large crabgrass (Figure 2) after 119 d, for treatments where fertilizer was not or was applied, respectively. These results suggest that as with the petri dish experiments, aged crabgrass seed loses much of its dormancy after approximately 8 mo of dark, dry storage at 5 C. The results also show that for fresh seed, fertilizer application increases seed germination and seedling emergence. In addition, for the large crabgrass experiments where fresh seed was used there was a significant site (soil type and turf sward) effect. Turf from the Guelph site consisted of a mix of perennial ryegrass, Kentucky bluegrass, and fine fescues, while turf from the Simcoe site also had some creeping bentgrass. The latter species has a stoloniferous growth habit and provided greater soil coverage (Turner, unpublished data) perhaps preventing more light from reaching the soil surface than occurred in the cores from the Guelph site. Previous studies have demonstrated how limiting light can limit large crabgrass germination (Taylorson and Brown 1977). In practical terms, however, this result may not be relevant, particularly in southern Ontario where fall emergence of summer annual grasses such as crabgrass is of no practical concern because summer annual weeds are killed by winter frost (Royer and Dickinson 1999). The practical result of these growth room experiments suggest that using a typical lawn fertilizer at its recommended rate on aged crabgrass seed (in the spring) would result in no difference in the levels of either large or small crabgrass seedling emergence.

**Fall and Spring Fertilization in Turfgrass.** In the outdoor experiment there was no significant effect of fertilizer application (either in fall or spring) on the recruitment level (number of seedlings recruited) of either smooth or large crabgrass. All crabgrass emergence curves could be pooled over fertilizer treatments (Figure 3). The null effect of fertilizer on crabgrass recruitment in the context of lawn management in northern North America is a novel report. This result appears to contrast to reports from other studies that suggest that fertilizer application may reduce crabgrass infestations (Dernoeden et al. 1993; Dunn et al. 1981 as cited in Busey 2003; Jagschitz and Ebdon 1985; Johnson 1981; Johnson and Bowyer 1982; Murray et al. 1983; Voigt et al. 2001). However, these studies often had inconsistent results between years and results were dependent upon other factors including mowing height. For example, Dernoeden et al. (1993) found that when no herbicides were used, small crabgrass presence (as measured using percentage of cover) was significantly reduced from 55 to 30% cover when urea-N fertilizer was applied at 196 kg N $ha^{-1}$ compared to 98 kg N $ha^{-1}$ within tall fescue (cultivar [cv.] 'Rebel II') turf mowed to 3.2 cm; however, this result was only significant in one of 3 yr. In addition, percentage of cover was only evaluated at the end of the season and small crabgrass was not significantly reduced within fertilized plots mowed to 5.5 or 8.8 cm. Similarly, Voight et al. (2001) determined that crabgrass (species not specified) percentage of cover (evaluated



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at the end of the season) within tall fescue (cv. blend 'Apache', 'Bonanza', and 'Olympic') turf was significantly reduced by 23% when 98, 195, or 293 kg N $ha^{-1}$ of fertilizer was applied compared to unfertilized control plots but, this result was significant in only one of 2 yr and there was no difference among fertilizer rates. The key difference between studies such as these and our study is that we measured emergence and not percentage of cover. Consequently, the conclusions of these studies may have been related to the impact of fertilizer on turf health or thickness and its effect on crabgrass infestation (as measured by percentage of cover) rather than any effect on crabgrass recruitment per se. The results of our experiment appear robust, especially in light of the fact that we tested fertilizer rates up to eight times the recommended rate. In addition, the field results corroborate the results of the in vitro and growth room experiments where we saw that the impact of fertilizer on crabgrass germination was related to dormancy breaking, which is only a factor for fresh seed.

The average total emergence for large crabgrass for the Guelph, Simcoe, and Woodstock sites was 2,824, 2,720, and 3,008 seedlings $m^{-2}$, respectively. This represents between 34 and 38% of total seed emergence. Seed viability was determined to be approximately 84% when seed was distributed in the fall and 82% after 9 mo of storage (the time when seedlings would have been first emerging in the spring). Therefore, the effective proportional emergence level for large crabgrass in this study was 41 to 46% of viable seed. For smooth crabgrass, the average total emergence for the Guelph, Simcoe, and Woodstock sites was 4,280, 4,008, and 4,184 seedlings $m^{-2}$, respectively. This represents between 50 and 54% of total seed emergence. Seed viability was determined to be approximately 91% when seed was distributed in the fall and 90% after 9 mo of storage. Therefore, the effective proportional emergence level for smooth crabgrass in this study was 56 to 59% of viable seed. The proportional emergence levels were relatively high compared to many annual weed species (Forcella et al. 1992). Crabgrass has been reported to recruit in relatively high proportions, for instance 41% as reported by Webster et al. (2003) and 80 to 90% by Cardina and Sparrow (1996); however, Forcella et al. (1992) reported proportional emergence of only 9% of the total seedbank for crabgrass species. There are no other reports of proportional recruitment of crabgrass in turf. The high proportion of emergence for both species in this study suggests that there may have been little room for improved microsite conditions to result in greater spring emergence. To homeowners, the proportion of recruitment in residential lawns in normal situations would likely appear much lower as competition would limit the survival of seedlings. A portion of the remaining seed that did not recruit may enter a period of secondary dormancy (Masin et al. 2006). Although longevity decreases over time due to germination, seed mortality, or removal due to causes such as predation by birds and insects (Crawley and Ross 1990), crabgrass can subsequently recruit beyond the first season (or seasons) with the onset of favorable conditions (Burnside et al. 1981; Egley and Chandler 1978; Masin et al. 2006; Peters and Dunn 1971). There is even one report of crabgrass persisting at low level for up to 10 yr (Burnside et al. 1981). The longevity of crabgrass within turf is important to consider when managing residential stands because the potential for infestation exists as long as there remains a viable seedbank.

There was no significant effect of fertilizer application on the rate of either large or smooth crabgrass emergence. For large crabgrass at the Guelph, Simcoe, and Woodstock sites, respectively, emergence started at a cumulative GDD of 313, 334, and 322 (this corresponded to Julian dates of 150, 151, and 152 or, between May 30 and June 1) (Figure 3a) and was beyond 50% by 732, 650, and 743 GDD for the Guelph, Simcoe, and Woodstock sites, respectively. There were small but statistically differences among sites in rates of large crabgrass emergence (Figure 3a). For the Guelph, Simcoe, and Woodstock sites, large crabgrass emergence ended at 1,383, 1,502, and 1,565 GDD, respectively, which corresponded to Julian dates of 231, 237, and 240, or between August 19 and August 28.

For smooth crabgrass, emergence at the Guelph, Simcoe, and Woodstock sites started at a cumulative GDD of 181, 224, 186, respectively (corresponding to Julian dates of 129, 137, and 130 or, between the dates of May 9 and May 17). The emergence rate at the Guelph and Woodstock sites was very similar but mid- to late-season emergence was delayed at the Simcoe site (a difference of approximately 100 GDD by the 75% emergence level), which may have been a result of dry conditions in this season being accentuated at the Simcoe site, which had a coarser soil texture than the other sites with likely less water holding capacity (Turner and Van Acker 2013). Smooth crabgrass emergence ended at a GDD of 1,447, 1,463, and 1,654 for the Guelph, Simcoe, and Woodstock sites, respectively, or



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between August 30 and September 4. The emergence rates for both large and smooth crabgrass were very similar to those reported by Turner and Van Acker (2013) on studies in residential lawns.

This study confirmed the positive effect of $KNO_3$ on the germination and emergence levels of fresh seed but not aged seed of both large and smooth crabgrass in petri dish experiments and we were able to demonstrate the same result in indoor experiments using turf cores and commercial lawn fertilizer. Extending this work outdoors to situations that would be relevant to typical turf stands in northern North America, we were able to show that there was no effect of fertilizer application on the emergence levels of large or smooth crabgrass. This study also confirmed that fall fertilizer applications do not affect emergence levels in the following spring. These results have practical relevance to homeowners and turf managers in this region because they are dealing with crabgrass emerging in the spring from seed shed the previous fall. The results also show that fertilizer can be used to aid turf quality and competitiveness without impacting true infestation level (density) of crabgrass in the spring.

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