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RESEARCH LETTER

Emergence of common lambsquarters (*Chenopodium album* L.) is influenced by the landscape position in which seeds developed

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Abstract

In a 2-yr field study, we evaluated the emergence and early growth of *Chenopodium album* L. (common lambsquarters) seedlings as affected by the landscape position in which the seeds (i) developed, (ii) overwintered, and (iii) were planted. Results indicated that a higher proportion of seeds originating from lower slope positions emerged compared with seeds originating from the backslope or upper slope. The timing of emergence was the same for all seed source locations. There was no influence of overwintering location on weed emergence. Regardless of the seed source, we observed faster emergence and growth of *C. album* planted in the lower slope, where soil conditions were more conducive to growth. These experiments will support the development of new strategies and decision aids to improve weed management.

1 | INTRODUCTION

Predictive models are under continual improvement to forecast the emergence and growth of weeds in agricultural fields. Knowledge of what, where, and when weeds will emerge drives effective weed management by any means. As precision agriculture approaches are developed to improve the efficiency of agricultural inputs, there is a need to better describe the factors that influence weed success. The dynamics of soil temperature, moisture, and other factors of the microsite (Bullied, Van Acker, & Bullock, 2012b and references therein) have been studied, but relatively little information exists regarding differences in weed emergence and growth as affected by the microsite in which the seeds developed and overwintered. We therefore evaluated the emergence and early growth of *Chenopodium album* L. (common lambsquarters) seedlings from seeds (i) produced (ii) overwintered, and (iii) sown in different landscape positions of a highly variable landform to examine potential topographic influences on subsequent weed emergence and growth.

2 | METHODS

Experiments were conducted in a landform in west-central Minnesota (45.65° N, 95.83° W) affected by long-term tillage erosion (Papiernik et al., 2009). The surface soil organic carbon concentration varied by a factor of eight across the landform (Figure 1). The northeast-facing slope was segmented into six landscape positions (summit through toeslope) as part of a larger study (Papiernik et al., 2009). For this study, the summit and shoulder were grouped as the upper slope, the upper and lower backslope were grouped as the backslope, and the footslope and toeslope were grouped as the lower slope (Figure 1).

Reciprocal planting studies were conducted in undisturbed (eroded) plots described in Papiernik et al. (2009). Selected *C. album* plants in three landscape positions (upper slope, backslope, and lower slope) were protected from herbicide application in 2008, and seeds were harvested from mature plants. The *C. album* seeds were overwintered in mesh bags buried at 5 cm depth in the same landscape position from which they were collected. Additionally, seeds originating from the upper slope were overwintered in the lower slope. Mesh bags were retrieved before spring tillage in 2009 and stored at 4°C until use. Germination of field-overwintered seeds was tested in sterilized blotter-lined Petri dishes.

After the crop was sown in 2009 (corn [*Zea mays* L.]) and 2010 (soybean [*Glycine max* (L.) Merr.]), 100 seeds originating from and overwintered in each landscape position were sown in duplicate 0.5 m × 0.5 m plots in each of the three landscape positions (upper slope, backslope, lower slope). Residue was removed and the soil was tilled using a manual rotary hoe and rake before sowing; soil was firmed with a roller following planting. Seeds were sown by hand at 1 cm depth in four rows per plot. Each plot included four rows of seeds, one from each of the four specific source/overwintering locations, as depicted in Figure 1; rows were randomly assigned within each plot.

Chenopodium album seeds were planted on 19 May 2009 and 2 June 2010 and were monitored until 19 June 2009 and 2 July 2010. Monitoring was discontinued when glyphosate was applied in 2009; an attempt was made to protect plants from the first herbicide application on 22 June 2010. Emergence was monitored every 1 to 7 d by counting the number of *C. album* plants emerged in each row. Plants were removed upon counting and cumulative emergence was calculated. A logistic model was fit to the cumulative emergence values and the time (d) required to achieve 50% emergence was used as an indicator of emergence timing. The first *C. album* plant to emerge in each row was not pulled, and its development was noted at the end of the monitoring period, including height and aboveground biomass. Plots were not protected from predation.

Surface soil moisture, temperature, and nutrients were measured in plots along the same hillslope as the weed study area. Surface soil (0–5 cm depth) volumetric water content was determined weekly using a dielectric impedance probe (HydraProbe, Stevens Water Monitoring Systems) in 2009. Soil temperature was monitored continuously at 5 cm depth using temperature loggers (Hobo, Onset Computer Corporation) in the shoulder and footslope positions in both 2009 and 2010. Soil nutrients (0–15 cm) were measured in spring using standard methods.

Results were analyzed by year using PROC GLIMMIX in SAS (SAS Institute, 2017), with seed source/overwintering location (four combinations) and planting location (three landscape positions) as independent fixed factors. Significant differences were determined using the Tukey test with $\alpha = 0.05$. Outliers were declared when the studentized residual was greater than 2.5; there was no more than one outlier per year per response variable. There was no significant interaction between seed source/overwintering location and planting location for any response variable.

Core Ideas
- Lambsquarters seeds originating from the lower slope had more successful emergence.
- There was no influence of overwintering location on lambsquarters emergence.
- Seeds planted in the lower slope had more and faster emergence, and faster growth.

3 | RESULTS AND DISCUSSION

3.1 | Growing conditions

In 2008, the year of weed seed production, soil moistures were very high during the early growing season and decreased dramatically in the summer drought. Rainfall totals measured at the site during the 2009 and 2010 studies were 23.5 and 84.4 mm, respectively.

There were large differences in soil properties as a function of landscape position (Figure 1; see also Papiernik et al., 2009). Surface soils in the lower slope were wetter and cooler than the upper and backslope positions. During the 2009 weed study, soil moistures in the upper slope and backslope were an average of 80 and 75% of those in the lower slope, respectively. The lower slope weed plots were not typically waterlogged during the growing season. In both 2009 and 2010, average daily temperatures were highest in the backslope and were an average 0.4°C cooler in the upper slope and 0.7°C (2009) to 1.2°C (2010) cooler in the lower slope. Nutrients measured by landscape position after fertilization in 2009 averaged 44–119 mg kg^{-1} for available N, 8–28 mg kg^{-1} for P, and 130–180 mg kg^{-1} for K; values for 2010 (no fertilizer applied) were 15–28 mg kg^{-1} for available N, 8–15 mg kg^{-1} for P, and 160–190 mg kg^{-1} for K, with the highest values always observed in the lower slope.

3.2 | Influence of weed seed source and overwintering locations

The location in which seeds developed significantly influenced seed weight and seedling emergence. The dry mass of 1000 seeds was significantly greater in the lower slope (0.63 g, SE 0.004) than the backslope (0.55 g, SE 0.003) and upper slope (0.51 g, SE 0.007). Germination was found to be uniform across seed source and overwintering sites.

In both years, seeds originating from lower slope positions had more successful emergence than seeds originating from the backslope or upper slope, regardless of where they were planted (Figure 2). The timing of emergence was the same for all seed source locations. These results suggest that *C. album* growing in the lower slope in 2008 may have been provisioned with more nutrients, altered hormone levels, and so

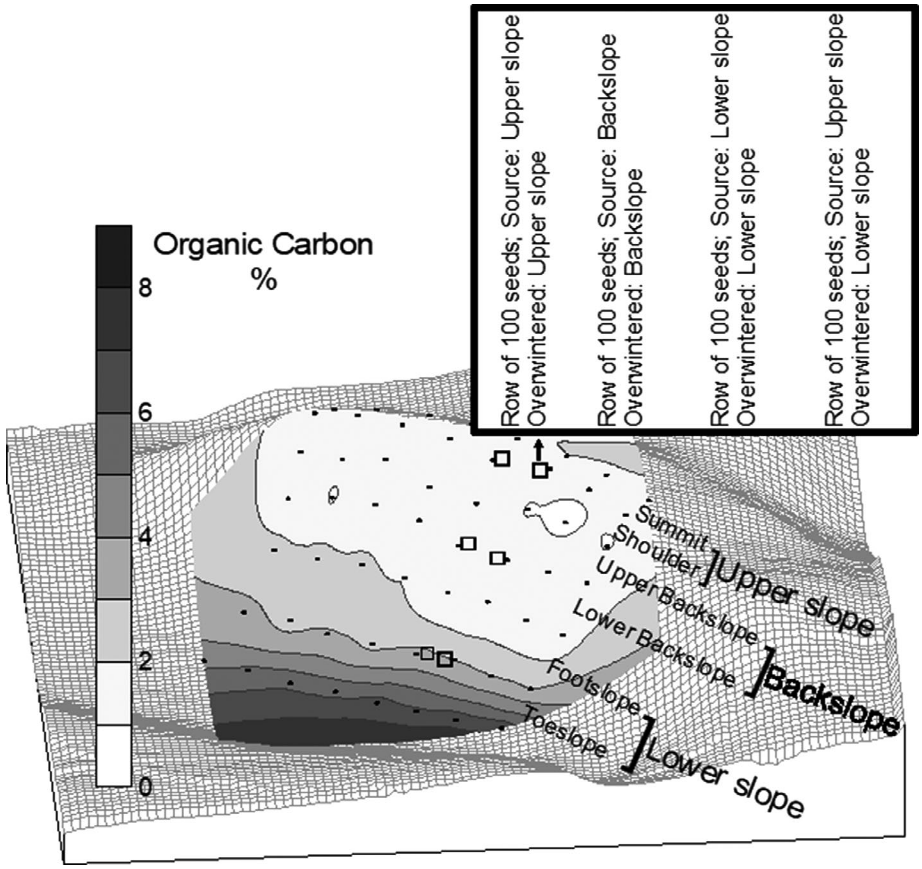

FIGURE 1 Location of weed plots (indicated by six boxes) and experimental set-up. Each of the plots included four rows of seeds as shown in the inset

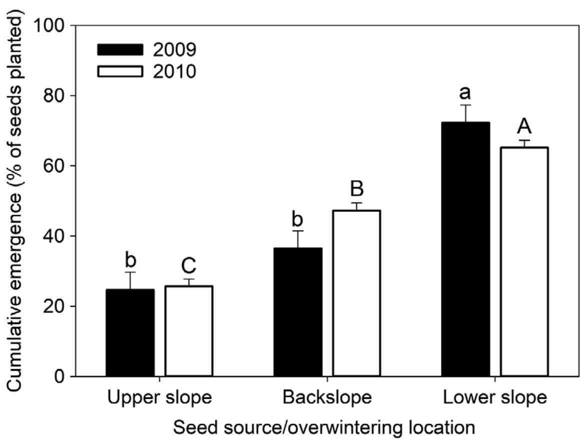

FIGURE 2 Cumulative emergence of *Chenopodium album* grown and overwintered in the upper slope, backslope, and lower slope of the hillside in Figure 1. Values are the mean across planting locations. Values followed by the same letter within each year are not significantly different ($p = 0.05$)

on, because of more favorable growing conditions in the lower slope compared with the eroded upper slope.

There was no influence of overwintering location on weed emergence: seeds sourced from the upper slope had the same cumulative emergence and time to 50% emergence whether they were overwintered in the upper slope or lower slope (data not shown). There were no differences in weed biomass or height as a function of seed source or overwintering location.

3.3 | Influence of weed seed planting location

Seeds planted in the lower slope tended to emerge more quickly and have more successful emergence than other landscape positions, although this was not always statistically significant (Figure 3). Differences in cumulative emergence among sites where seeds were planted (a factor of about 1.2; Figure 3) were much smaller than differences among sites where seeds had developed (a factor of >2.5, Figure 2). Seeds were planted at a uniform (1 cm) depth and with good seed-to-soil contact, which should have favored emergence.

In 2009, *C. album* planted in the lower slope grew more rapidly than those planted in the backslope and upper slope. This effect was not significant in 2010, when deer browsing and possible herbicide damage were noted in upper and lower slope plots. In 2009, *C. album* planted in the upper slope and backslope had <20% the dry biomass and were <50% the height of plants grown in the lower slope. These differences are likely due to the better growing environment in the lower slope.

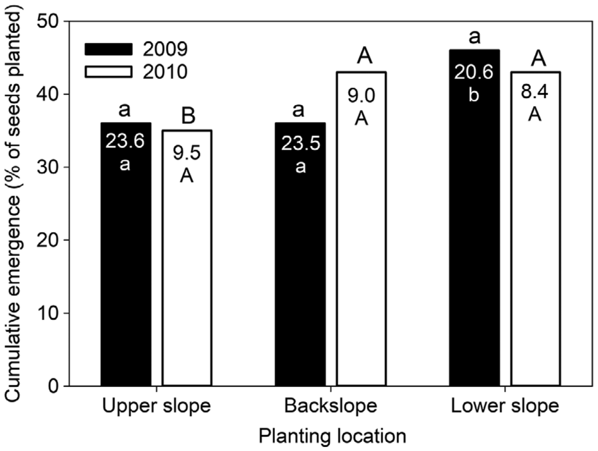

FIGURE 3 Cumulative emergence (bars) and time (d) required to reach 50% of maximum emergence (numbers within bars) of *Chenopodium album* planted in the upper slope, backslope, and footslope of the hillside in Figure 1. Values are the mean across seed source/overwintering locations. Values followed by the same letter within each year are not significantly different ($p = 0.05$)

Other experiments that evaluated weed seedling establishment as a function of landscape position reported varying results. Bullied, Van Acker, and Bullock (2012a) reported that differences in soil physical properties, temperature, and moisture on a hillslope in Manitoba did not produce differences in emergence timing or cumulative emergence of spring wheat (*Triticum aestivum* L.) used as a weed surrogate. Studies in Nebraska showed that establishment of annual weed populations varied with topographic position but not in a consistent way, in part because high soil moisture in some low-lying areas inhibited establishment (Dieleman, Mortensen, Buhler, & Ferguson, 2000; Dille, Mortensen, & Young, 2002). These Nebraska studies evaluated weed populations in producer fields, not establishment of purposely planted weed seeds. Our experiments were conducted in fields with good overall weed control. The *C. album* plants were protected from herbicide application in 2008 to produce seeds for the experiment. The results of our study suggest that perhaps some of the spatial variability observed in weed populations (Albrecht & Pilgram, 1997; Bullied et al., 2012a; Cardina, Sparrow, & McCoy, 1995; Dieleman et al., 2000; Dille et al., 2002) is due to more successful emergence of seeds produced in landscape positions providing favorable conditions and that reducing dispersal of these seeds may be an important mechanism influencing overall weed management.

The differences in the timing and extent of *C. album* emergence and growth as a function of seed source and planting location have implications for precision agriculture approaches that attempt to make the most efficient use of agrochemical and other inputs. These experiments will aid the development of biological models of *C. album* and other weeds and thereby support efforts to devise new strategies and decision aids to improve weed management.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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