Sugarbeet is More Competitive for Nitrogen than Common Lambsquarters and Powell Amaranth

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ABSTRACT

Nitrogen (N) is an important nutrient to maximize sugarbeet yield, yet improper N application timings or rates may negatively impact sugarbeet grown in competition with weeds. A greenhouse study was conducted to examine the effect of three N rates (0, 67, and 134 kg N ha^{-1}) on the competitive ability of common lambsquarters and Powell amaranth grown with glyphosate-resistant sugarbeet at various proportions. Sugarbeet and Powell amaranth had incrementally higher N concentrations as N rate increased, while common lambsquarters had N concentrations that were not significantly different at 67 and 134 kg N ha^{-1} rates. Sugarbeet had greater N concentrations than common lambsquarters at all N rates and higher N concentrations than Powell amaranth at 67 and 134 kg N ha^{-1}. Sugarbeet had higher relative N assimilations and greater relative biomass yields at all N rates than both weed species. Although sugarbeet was more competitive than common lambsquarters and Powell amaranth for N, uncontrolled weeds reduce available water, light and nutrients to sugarbeet, and weed-crop interactions in field settings may produce different results than controlled environments. Therefore, timely weed control strategies and appropriate N management should be implemented to avoid negative effects of competition with common lambsquarters and Powell amaranth on sugarbeet growth and production.

Additional Key Words: *Beta vulgaris* L. 'Crystal 827RR;' *Chenopodium album* L.; *Amaranthus powellii* S. Watson; weed density; nitrogen rate; nitrogen assimilation.

Effective and appropriately timed weed control strategies are critical in cropping systems because weeds compete with crops for water, nutrients, and light (Schweizer and May, 1993). Nitrogen is an important nutrient applied to crops to obtain high yields, and it is the most significant nutrient for sugarbeet (*Beta vulgaris* L.) (Draycott,1993). An adequate quantity of N is required early in the growing season to promote canopy development, and N should be available throughout the growing season to maintain the canopy and assist with root growth and sucrose production (Armstrong et al., 1986; Draycott, 1993; Scott and Jaggard, 1993). Nitrogen application in sugarbeet however, must be balanced to achieve high quality root yields because excess N reduces juice purity and sucrose extraction (Draycott, 1993).

Weeds are capable of assimilating large amounts of N, especially at high N rates. Both common lambsquarters (*Chenopodium album* L.) and redroot pigweed (*Amaranthus retroflexus* L.) are highly responsive to N (Blackshaw et al., 2003; Bast, 2012). Blackshaw et al. (2003) conducted an experiment in controlled environmental conditions to determine N assimilations of 23 weed species at various N rates. At 120 mg N kg^{-1} soil, 17 weed species assimilated levels of N that were similar to the levels of N assimilated by common lambsquarters and redroot pigweed. At 240 mg N kg^{-1} soil however, only three weed species, hairy nightshade (*Solanum sarrachoides* Sendtner), redstem filaree (*Erodium cicutarium* (L.) L'Her. ex Air) and round-leaved mallow (*Malva pusilla* Sm.), assimilated levels of N that were similar to the levels of N assimilated by common lambsquarters and redroot pigweed, indicating that common lambsquarters and redroot pigweed were two of the most responsive weed species to increasing levels of N in the study.

How weeds respond to increasing N rates is dependent on the particular species and the time of the N application. Redroot pigweed shoot N concentration increased 31 and 107% as N rate increased from 60 to 120 and 60 to 240 mg kg^{-1} soil, respectively, when grown in competition with spring wheat (*Triticum aestivum* L. 'AC Barrie') (Blackshaw and Brandt, 2008). However, shoot N concentrations for Persian darnel (*Lolium persicum* Boiss. & Hohen. ex Boiss), a weed species that is characterized as having a low response to N, only increased 23 and 51% for the same increases in N rates (Blackshaw and Brandt, 2008). Other studies have shown that common lambsquarters was more competitive with sugarbeet when 120 kg N ha^{-1} was applied at the 4- to 6-leaf sugarbeet growth stage, compared with later N applications at the 10- to 12-leaf sugarbeet growth stage (Paolini et al., 1999).

The commercialization of glyphosate-resistant sugarbeet has changed how growers approach weed management. The use of glyphosate for weed control provides growers with greater flexibility in application timings than traditional methods for controlling weeds in conventional sugarbeet (Kniss et al., 2004). Because glyphosate can control larger weeds, growers are able to delay their initial herbicide application, which allows weeds to compete with crops for valuable resources, such as N, for a longer period of time. Understanding how weeds compete with sugarbeet for N will help provide growers information that would be useful in devising appropriate weed and fertilizer management strategies.

Recent field experiments in Michigan showed that weeds competed with sugarbeet for N and resulted in reduced sugarbeet yields and recoverable white sucrose per hectare (RWSH) (Spangler, 2012). Nitrogen assimilation by weeds (< 30 cm tall) was 3 times greater than sugarbeet (< 12 leaves) at 0, 67, 100, and 134 kg N ha^{-1}, and 4 times greater than sugarbeet at a split application of N totaling 134 kg N ha^{-1} (67:67 kg N ha^{-1}) (Spangler, 2012). Early weed control improved sugarbeet yield and RWSH, and highest yields and RWSH were achieved when weeds were controlled prior to reaching 2 cm tall at three of the four site-years (Spangler, 2012).

Additional experiments examining the effects of N rate on common lambsquarters and Powell amaranth in competition with sugarbeet would be beneficial because those weed species are most problematic in Michigan sugarbeet fields (G. Clark, Agronomist, Michigan Sugar Company, Bay City, MI, personal communication). Therefore, the objective of this research was to determine the effect of N application rate on the competitive ability of two problematic weeds, common lambsquarters and Powell amaranth, grown alone and with sugarbeet.

MATERIALS AND METHODS

A greenhouse study was conducted in 2011 at Michigan State University in East Lansing, Michigan. The experiment was arranged in a randomized complete block design, replicated five times and repeated in time. Treatments included glyphosate-resistant sugarbeet competing with either common lambsquarters or Powell amaranth at three N fertilizer rates. Sugarbeet and each weed species were grown in a replacement series design at proportions of 100:0, 75:25, 50:50, 25:75, and 0:100 with a total of 8 plants pot^{-1}. Nitrogen fertilizer rates were 0, 67, and 134 kg N ha^{-1}.

Glyphosate-resistant sugarbeet 'Crystal RR 827' (ACH Seeds Inc., PMB 305, 574 Prairie Center Drive #135, Eden Prairie, MN 55344), common lambsquarters, and Powell amaranth seeds initially were planted into flats (Landmark Plastic, 1331 Kelly Avenue Akron, OH 44306) filled with potting media (Michigan Grower Products, Inc., 251 McCollum, Galesburg, MI 49053) and placed in the greenhouse. Greenhouse temperatures were maintained at 25 ± 5°C with a 16-h photoperiod of natural sunlight and supplemental lighting was provided at 1,000 µmol/m^2/s photosynthetic photon flux. Individual 3.1 L pots (ITML Horticultural Products, 75 Plant Farm Blvd., Brantford, Ontario, N3T 5M8) were filled with 2.6 kg of steam sterilized Spinks loamy sand soil (sandy, mixed, mesic Lamellic Hapludalfs) with a pH of 6.7, 2.2% organic matter, and total N content of 0.5 g kg^{-1} for the first experiment, and a pH 7.3, 2.1% organic matter, and total N content of 0.6 g kg^{-1} for the second experiment. Each pot was watered to bring the soil water content to field capacity. Aqueous solutions of urea (46-0-0) containing the desired amount of N were uniformly pipetted onto the soil surface and incorporated with approximately 150 mL of water.

When sugarbeet, common lambsquarters and Powell amaranth were at the cotyledon stage (approximately 10 d after planting and 2 to 3 d after N application) they were transplanted into the N amended soils. Eight plants pot^{-1} at the 100:0, 75:25, 50:50, 25:75, and 0:100 (sugarbeet:weeds) proportions were transplanted at an equidistant spacing around the pots' circumference, keeping spacing between species equal. Pots were watered daily using individual sub-irrigation units and rotated once a week to avoid possible differences in lighting and temperature among the treatments.

Glyphosate-resistant sugarbeet, common lambsquarters, and Powell amaranth plants were harvested 28 d after transplanting when sugarbeet were at the 6- to 8-leaf stage after rapid N assimilation by sugarbeet, which occurs at the 4- to 5-leaf growth stage (Scott and Jaggard, 1993). Common lambsquarters were 8-10 cm tall and exhibited 20-30 leaves, while Powell amaranth was 10-12 cm tall and exhibited 10-20 leaves. Excess soil was removed from the roots with water, and roots were blotted dry with paper towel. The entire plant (shoots and roots) was oven-dried at 66°C for 7 d and weighed. Plant samples were ground to pass through a sieve < 0.5 mm. Total N content was determined by the micro-Kjeldahl digestion method (Bremner, 1996; Jung et al., 2003) and colorimetric analysis through a Lachat rapid flow injector autoanalyzer (Lachat Instruments, Milwaukee, WI). Nitrogen assimilation by each species was calculated by multiplying the plant biomass by nitrogen concentration.

Data were analyzed using the PROC MIXED procedure in SAS 9.3 (SAS® 9.3 Software, SAS Institute Inc, 100 SAS Campus Drive, Cary, NC 27513). Normality of the residuals was evaluated by examination of normal probability and stem-and-leaf plots. Homogeneity of the variances was evaluated by the Levene's test ($p < 0.05$) and they were grouped to improve the model. An analysis of variance was performed and treatment means were compared using Fisher's Protected LSD at the $p < 0.05$ significance level. Data were combined over trials because there was not a significant treatment by trial interaction, and the data were presented for main effects when interactions were not significant. Nitrogen assimilation and biomass data of sugarbeet, common lambsquarters and Powell amaranth were converted to relative N assimilation (RN) or relative yield (RY) to produce replacement-series diagrams (Cousens, 1991; Weigelt and Jolliffe, 2003; Blackshaw and Brandt, 2008) to determine the competitiveness of each species in mixture compared with a monoculture at each of the three N fertilizer rates using the following equation: RN or RY = N assimilation or yield in mixture/N assimilation or yield in monoculture.

Similar to Blackshaw and Brandt (2008), weed aggressivity index

(AI) values were calculated as an additional measurement of species competitiveness when grown in a mixture. Weed AI values that are above zero indicated that the weed was more competitive than sugarbeet and weed AI values that are less than zero indicated that the weed was less competitive than sugarbeet. Weed AI values are calculated for nitrogen assimilation and biomass accumulation for each species using the following equation: AI = (yield of weed species in mixture/yield of weed species in monoculture) - (yield of sugarbeet in mixture/yield of weed species in mixture).

RESULTS AND DISCUSSION

Relative Nitrogen Assimilation

Sugarbeet was more competitive than common lambsquarters in terms of relative N assimilation at all N rates (Figure 1). As N rate increased it appeared that sugarbeet was more competitive, especially at the 134 kg N ha^{-1} rate. However, there was no difference in the magnitude of sugarbeet competitiveness with increasing N rates, because the common lambsquarters' aggressivity index (AI) values were not significant (Table 1). Sugarbeet N assimilation also was superior to Powell amaranth when grown in a mixture (Figure 1). As N rate increased, sugarbeet became more competitive with Powell amaranth. Powell amaranth AI values were -0.30, -1.12, and -2.32 at 0, 67, and 134 kg N ha^{-1}, respectively (Table 1). The values indicate sugarbeet was able to capture progressively more soil N than Powell amaranth as N fertilizer rate increased.

Common lambsquarters and redroot pigweed have been reported to be luxury consumers of N at high N rates (Blackshaw et al., 2003). It is expected that Powell amaranth also would be responsive to N at higher N rates because it is in the same family as redroot pigweed (*Amaranthus spp.*). Blackshaw and Brandt (2008) determined that N assimilation of redroot pigweed increased as N rate increased from 60 to 240 mg N kg^{-1} soil when grown in competition with spring wheat. At 60 and 120 mg N kg^{-1} soil, N assimilation by redroot pigweed was inferior to spring wheat, but at the 240 mg N kg^{-1} rate, N assimilation by redroot pigweed was slightly superior, indicating the weed was highly responsive to the increasing N rates.

Unlike Blackshaw and Brandt's (2008) results, the relative N assimilation by common lambsquarters and Powell amaranth was inferior to sugarbeet at all N rates, and both weed species were less competitive with sugarbeet as N rate increased. Sugarbeet may have had higher relative N assimilation than both weed species because sugarbeet rapidly assimilates N at the 4- to 5-leaf stage for canopy development (Scott and Jaggard, 1993). In this study, individual sugarbeet plants assimilated greater quantities of N than both weed species (data not shown), which most likely contributed to higher relative N assimilations by sugarbeet. Nitrogen assimilation by sugarbeet also may have been greater than both weed species due to the placement

Figure 1. Relative nitrogen assimilation of sugarbeet (●) competing with common lambsquarters (○) and sugarbeet (▲) competing with Powell amaranth (△) at 0, 67, and 134 kg N ha^{-1}. Vertical bars represent standard error of the mean.

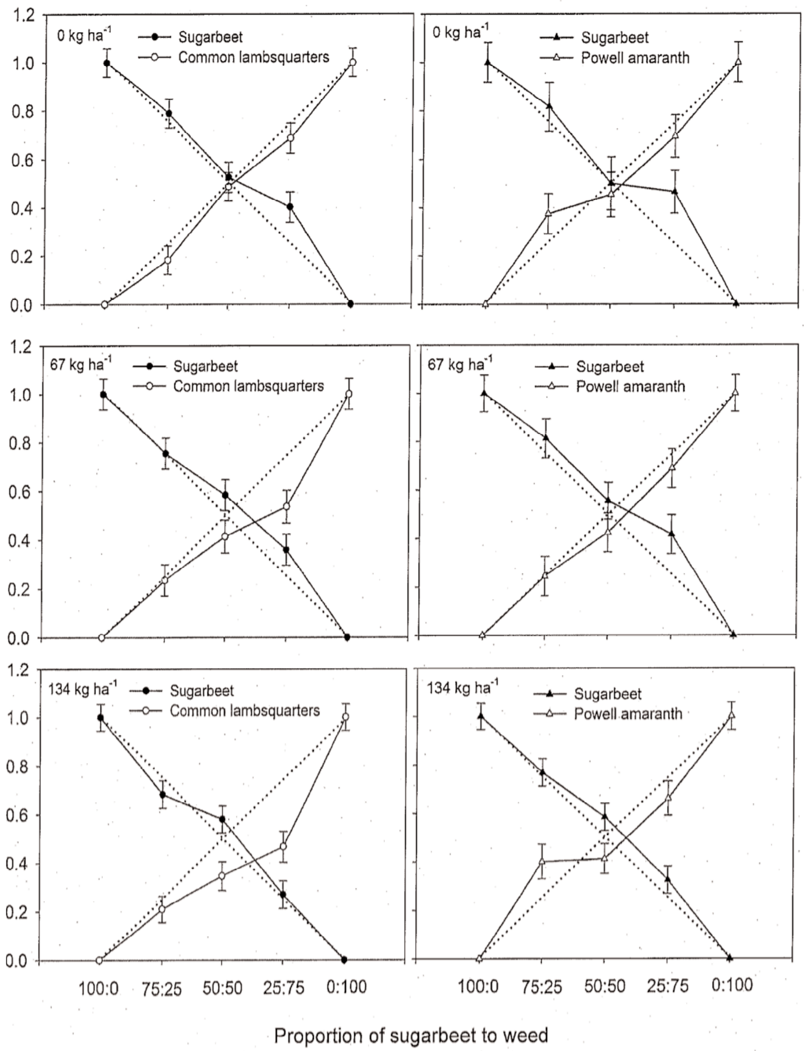


Table 1. Effect of nitrogen rate on common lambsquarters and Powell amaranth aggressivity index (AI) values† determined from sugarbeet and weed relative N assimilation data.

Nitrogen Rate	Common lambsquarters	Powell amaranth
0 kg ha^{-1}	- 0.74 a*	- 0.30 a
67 kg ha^{-1}	- 0.92 a	- 1.13 ab
134 kg ha^{-1}	- 1.74 a	- 2.32 b

† Weed AI values that are above zero indicated that the weed is more competitive than sugarbeet and weed AI values that are less than zero indicated that the weed is less competitive than sugarbeet.
* Means followed by the same letter within a column are not statistically different at the $p \leq 0.05$ level of significance according to Fisher's Protected LSD.

and proportion of weed species in the pots. In field settings, broadcast applications of N often favor weed N assimilation and growth because the N is not placed close to the sugarbeet plant (Blackshaw et al., 2002; Stevens et al., 2007), and the density of weeds can be much higher than crop density (Bast, 2012). In our study however, N availability for sugarbeet and weeds was similar because the plants were transplanted at an equidistant spacing between species and the proportion of weeds to sugarbeet was very low.

Nitrogen concentrations of sugarbeet were higher than common lambsquarters at all N rates and greater than Powell amaranth at 67 and 134 kg N ha^{-1} (Table 2). Increases in the magnitude of N concentrations in both weed species were noted when N rate was increased from 0 to 67 kg N ha^{-1} and only for Powell amaranth when N rate increased from 67 to 134 kg N ha^{-1}. At higher N rates, both shoot N concentration and N assimilation of redroot pigweed were more responsive than spring wheat (Blackshaw and Brandt, 2008). Blackshaw and Brandt (2008) noted that redroot pigweed shoot N concentration increased 107% when N rate was increased from 60 to 240 mg N kg^{-1} soil, while spring wheat shoot N concentration only increased 71%. In our study, the percentage increase of N concentration from 0 to 134 kg N ha^{-1} in sugarbeet was greater than common lambsquarters and Powell amaranth, and the relative N assimilation of sugarbeet was always superior to both weed species. Sugarbeet and common lambsquarters N concentrations increased 27 and 21%, respectively, while sugarbeet and Powell amaranth N concentrations increased 50 and 36%, respectively.

Table 2. Effect of nitrogen rate on nitrogen concentrations of sugarbeet, common lambsquarters, and Powell amaranth.

Nitrogen rate	Sugarbeet	Common lambsquarters	Sugarbeet	Powell amaranth
	% N		% N	
0 kg ha^{-1}	1.50 d*	1.40 e	1.40 cd	1.30 d
67 kg ha^{-1}	1.70 b	1.60 cd	1.70 b	1.50 c
134 kg ha^{-1}	1.90 a	1.70 bc	2.10 a	1.80 b

* Means followed by the same letter within a section are not statistically different at the $p < 0.05$ significance level according to Fisher's Protected LSD.

Relative Yield

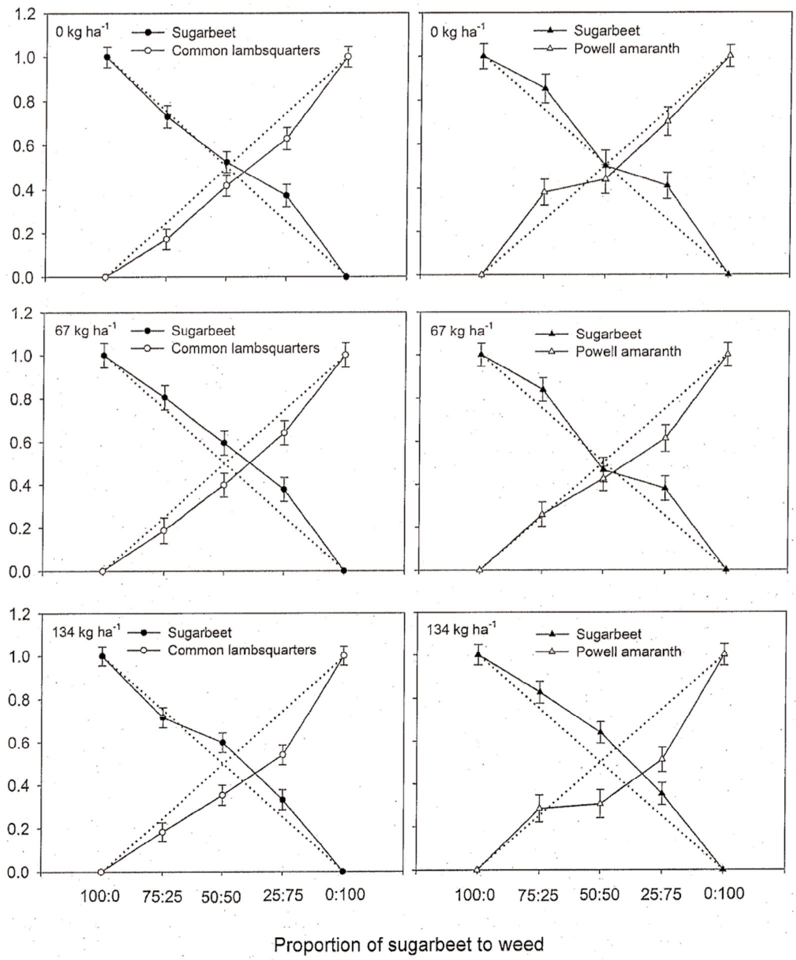
The relative yield of sugarbeet, common lambsquarters, and Powell amaranth biomass was similar to relative N assimilation for each of these species (Figure 2). Sugarbeet was more competitive than common lambsquarters in terms of relative yield, and there were no differences in competition across all N rates. Common lambsquarters AI values indicate N rate did not influence the competitive ability of the weed (Table 3).

Table 3. Effect of nitrogen rate on common lambsquarters and Powell amaranth aggressivity index (AI) values† determined from sugarbeet and weed relative yield data.

Nitrogen Rate	Common lambsquarters	Powell amaranth
0 kg ha^{-1}	- 0.79 a*	- 0.42 a
67 kg ha^{-1}	- 0.94 a	- 0.96 ab
134 kg ha^{-1}	- 1.21 a	- 2.21 b

† Weed AI values that are above zero indicated that the weed is more competitive than sugarbeet and weed AI values that are less than zero indicated that the weed is less competitive than sugarbeet.
* Means followed by the same letter within a column are not statistically different at the $p \leq 0.05$ level of significance according to Fisher's Protected LSD.

Figure 2. Relative yield of sugarbeet (●) competing with common lambsquarters (○) and sugarbeet (▲) competing with Powell amaranth (△) at 0, 67, and 134 kg N ha-1. Vertical bars represent standard error of the mean.



The relative yield of sugarbeet was superior to Powell amaranth at all N rates, with the competitive ability of sugarbeet increasing with increasing N rates (Figure 2). Powell amaranth AI values were -0.41, -0.96, and -2.21 at 0, 67, and 134 kg N ha^{-1}, respectively (Table 3). These values indicate that Powell amaranth was less competitive with sugarbeet at higher N rates, which is reflected in Figure 2. Many Powell amaranth plants were injured by N at the 134 kg N ha^{-1} rate, which may have impacted Powell amaranth's competitive ability with sugarbeet (personal observation). Injured plants were stunted and had slower rates of growth than healthy plants for a period of time after transplanting. Neither sugarbeet nor common lambsquarters were negatively affected by the highest N application rate.

The relative N assimilations and relative yields of common lambsquarters and Powell amaranth were inferior to sugarbeet at all N rates; however, Powell amaranth may be able to compete with sugarbeet more successfully than common lambsquarters. At 0 and 134 kg N ha^{-1}, the relative yield of Powell amaranth was higher than expected at the 75:25 proportion, while common lambsquarters relative yield was lower than expected at all N rates and proportions (Figure 2). Powell amaranth may have been more competitive than common lambsquarters in terms of relative yield due to its morphology and greater above-ground competition. Powell amaranth was slightly taller than common lambsquarters and its leaf area was greater (data not shown). Tall weeds shade the sugarbeet canopy, reducing light interception and sugarbeet biomass production (Dawson, 1965; Weatherspoon and Schweizer, 1969; Scott and Jaggard, 1993). Bast (2012) noted that redroot pigweed shoot biomass was greater than common lambsquarters 3 weeks after emergence at 0 and 67 kg N ha^{-1}, suggesting that redroot pigweed exhibits more above-ground competition than common lambsquarters early in the growing season. It is expected that Powell amaranth also would exhibit greater shoot biomass than common lambsquarters early in the growing season because it is in the same family as redroot pigweed.

In summary, sugarbeet had increased competitive ability as N rate increased, and the crop was superior to common lambsquarters and Powell amaranth in terms of relative N assimilation and yield. Sugarbeet relative N assimilation may have been greater than both weed species due to its rapid assimilation of N at the 4- to 5-leaf stage for canopy development (Scott and Jaggard, 1993). Powell amaranth competed with sugarbeet more effectively than common lambsquarters in terms of relative yield, possibly because its tall height and large leaf area shaded the sugarbeet canopy, reducing sugarbeet light interception and biomass production (Dawson, 1965; Weatherspoon and Schweizer, 1969; Scott and Jaggard, 1993). Additionally, greater above-ground competition of Powell amaranth compared to common lambsquarters also may have increased the weed's competitive ability (Bast, 2012).

Although sugarbeet was more competitive than common lambsquarters and Powell amaranth, uncontrolled weeds reduce available water, light and nutrients to sugarbeet (Schweizer and May, 1993). Weed-crop interactions in field settings may produce results that differ from controlled environments because weed density in fields can be very high, causing weeds to assimilate high quantities of N (Bast, 2012; Spangler, 2012). Therefore, timely weed control strategies and appropriate N management should be implemented to avoid negative effects of competition with common lambsquarters and Powell amaranth on sugarbeet growth and production.

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