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# The Effects of Increasing Grazing Height on Establishment of Pasture Weeds in Management-Intensive Rotationally Grazed Pastures

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Weeds can infest management-intensive grazed pastures and impact forage quantity, forage quality, and animal health. Common burdock, plumeless thistle, and Canada thistle are three common pasture weeds in the midwestern United States that are managed to avoid these impacts. Experiments were established at two sites to determine if increasing grazing heights from fall through summer would reduce emergence and survival of burdock, plumeless thistle, and Canada thistle seedlings. Five simulated grazing heights (5, 10, 15, and 20 cm and a not-clipped treatment) were implemented in October 2008 and repeated in May through August. Density of all species was reduced from May to September, with reductions ranging from 65 to 78%, regardless of treatment. Treatments that left at least 15 cm of residual grass had reduced densities of burdock and Canada thistle compared to the 10-cm treatment. Regression analysis demonstrated that reduction in burdock and summed planted weed density was related to increased intercepted photosynthetically active radiation from forage in April. However, total biomass yield was reduced up to 60% when grazing heights were increased from 5 to 20 cm, although differences were only observed at the fall and early spring grazing events. Relative forage quality (RFQ) was similar across treatments, except at the third grazing event for which the 15 and 20-cm treatments had reduced RFQ compared with other treatments. Results suggest that increasing grazing heights can reduce emergence and survival of burdock and Canada thistle but can also result in a reduction in forage quantity in the fall and early spring.

**Nomenclature:** Canada thistle, *Cirsium arvense* (L.) Scop.; common burdock, *Arctium minus* Bernh.; plumeless thistle, *Carduus acanthoides* L.

**Key words:** Light interception, weed emergence, weed survival.

Prevention of weed establishment is a key benefit of management-intensive rotationally grazed (MiRG) pastures compared with continuously grazed pastures and other agronomic crops. Forage species can reduce the competition from weeds if managed correctly (Grace et al. 2002; Wardle et al. 1995). However, MiRG pastures are not immune to weed infestations, and invasion can occur over time due to mismanagement or under-utilization of a particular weed (Blanchet et al. 2003).

Weed species can reduce yield and utilization of forages causing losses in animal performance (Seefeldt et al. 2005). For example, Canada thistle infestations of 20 shoots $m^{-2}$ have been documented to reduce forage yield by 868 kg $ha^{-1}$ (Grekul and Bork 2004). Although animals will consume weeds, palatability is often very low (Marten et al. 1987). Low palatability of weeds resulting in reductions in utilization of forage by 18 to 47% have been demonstrated with Canada thistle (De Bruijn and Bork 2006). Other species with large spines e.g., cocklebur (*Xanthium strumarium* L.), bull thistle [*Cirsium vulgare* (Savi) Ten.] have been completely rejected (Liebman et al. 2001; Taylor et al. 2008).

While herbicides are an effective strategy in managing pasture weeds, they are not a viable option in several situations. First, organic pastures have few herbicides registered for use, and registered organic products are not selective or effective on typical weed species present in pastures. Additionally, many pastures contain a mixture of forage grasses and legumes, and in these areas the presence of legumes prevents broadcasting herbicides because they also suppress desirable legumes (Sellers et al. 2007). Both of these scenarios are common; therefore, alternative management methods are required for these systems.

Within Wisconsin, common burdock, plumeless thistle, and Canada thistle were identified by crop consultants as pasture weeds that were difficult to control (Renz 2006). These species begin to germinate in March through early April in Wisconsin, and seeds that emerge at this early timing typically survive to flower in future years compared with later emerging cohorts (M. J. Renz, personal observation). This germination timing offers an ideal opportunity to prevent weed establishment as research has shown that light improves establishment of burdock, plumeless and Canada thistle by increasing germination rates and/or enhancing survival (Cross 1931; Feldman et al. 1994; Maguire and Overland 1959). By increasing the amount of forage present, we hypothesize that less light will contact the soil surface in MiRG pastures and this, in combination with competition from forage plants, will result in reduced weed establishment and survival. This hypothesis is supported by observations in continuously grazed pastures where dense forage plant canopies had reduced plumeless and musk thistle (*Carduus nutans* L.) plant densities (Wardle et al. 1992). Authors attributed this reduction to changes in light intercepted but did not measure this relationship. Others have related success of establishment of plumeless thistle to increased light availability in abandoned pastures (Feldman et al. 1994). Annual production systems have measured this relationship as winter wheat fields reduced plumeless thistle emergence compared with a bare-ground control (Kruk et al. 2006). Additional research is needed in MiRG pastures before recommendations can be created to benefit production.

The objectives of this study were to determine if increasing grazing height in fall through summer would decrease establishment of burdock, plumeless thistle, and Canada thistle in MiRG and how light interception from the residual forage in the spring is associated with weed establishment. Since this new management strategy could affect forage yield and quality, an additional objective was to measure if these variables differed between treatments.

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## Materials and Methods

**Sites.** Field experiments were conducted from the fall of 2008 through the summer of 2009 at Arlington Agricultural Research Station (43.18°N, 89.20°W) and Franbrook Research Farm (42.44°N, 89.45°W) in Arlington and New Glarus, WI, respectively. The soil type at Arlington is a Ripon silt loam and common forage species consisted of perennial ryegrass (*Lolium perenne* L.) and tall fescue (*Festuca arundinacea* Schreb.). During the experiment the pasture was fertilized with ammonium nitrate at 56 kg N $ha^{-1}$ on May 22, 2009, and July 1, 2009. The soil type at the Franbrook Research Farm is an Arenzville silt loam and the pasture consisted of meadow fescue [*Schedonorus pratensis* (Huds.) P. Beauv.], perennial rye, orchard grass (*Dactylis glomerata* L.) and Kentucky bluegrass (*Poa pratensis* L.). The study at Franbrook did not receive any fertilization during the experiment.

**Simulated Grazing.** This study used simulated grazing (clipping) to implement treatments. Clipping of pastures has been documented to affect pastures differentially compared with animals grazing. Grazed pastures can result in higher seed germination (Bakker et al. 1983; Willems 1983), increased compaction (Muto and Martin 2000), different nutrient levels (Sigua et al. 2006; Williams and Haynes 1990), and increased forage production compared with mowing (Matches 1992). Despite these limitations, we utilized clipping to simulate grazing to conduct these experiments. While results may differ in grazed areas, clipping allowed us to vary the canopy and resulting light interception to test our hypothesis on a range of treatments that otherwise would not have been possible due to economic and infrastructural limitations to using livestock (Kirby et al. 1997; Rinella and Hileman 2009).

**Research Design.** Five simulated grazing heights were established at each site in October of 2008 and repeated at typical grazing intervals throughout 2009 in a randomized complete block design with four replications. Plots were 6 by 6 m and fenced to separate treatments from active grazing in nearby pastures. Treatments consisted of clipping grass, removing clipped biomass and leaving a residual height of 5 cm (extreme grazing), 10 cm (heavy grazing), 15 cm (typical grazing), or 20 cm (light grazing). A not-clipped (not grazed) treatment was also included for comparison. Each plot was cut to the treatment height and then allowed to regrow during the rest period until the next simulated grazing event. Simulated grazing was conducted as close as possible to actual grazing timing for rotationally grazed pastures in this region, but length of rest period varied between 28 and 34 d throughout the summer based on plant growth, which resulted in each height being grazed four times a year. To ensure adequate weed populations, 66 pure live seeds $m^{-2}$ of burdock, plumeless thistle, and Canada thistle were individually collected within a 50-ha radius. Each of these species was broadcasted into the plots in October 2008, resulting in an addition of 264 pure live weed seeds $m^{-2}$ for each plot.

**Measurements.** Weed emergence and survival of seeded species was estimated in May 2009 and repeated in September. Burdock, plumeless thistle, and Canada thistle population density (number of plants per unit area) was estimated by randomly placing a 0.125-$m^2$ quadrat in each plot four times and counting emerged species. Intercepted photosynthetic active radiation (iPAR) was determined in early April, following snow melt, but prior to any weed or grass growth and repeated in May just prior to implementing the first simulated grazing in 2009. iPAR was calculated from measurements with an AccuPAR model LP-80 ceptometer (AccuPAR model LP-80 ceptometer, Decagon Devices, Pullman, WA) with integrated probe and microcontroller. Three readings were averaged above canopy and three below canopy from five locations within each plot at each site. The amount of light the pasture forage canopy intercepted (iPAR) was calculated using the following equation (Colquhoun et al. 2009):

$$\% \text{ light interception (iPAR)} = [(\text{above canopy PAR} - \text{below canopy PAR})/\text{above canopy PAR}] \times 100 \qquad [1]$$

Forage yield was estimated at each simulated grazing event by collecting forage from four randomly placed 0.125-$m^2$ quadrats in each plot. Within each quadrat forages were harvested to the treatment height, collected, dried at 50 C for 1 week, and weighed to determine yield for various treatments and timings. Forage collected in the spring and summer was used to determine forage quality using near infrared spectrometry (NIRS System Model 6500 Instrument, Foss NIRSystems, Laurel, MD) with a wavelength range of 800 to 2500 nanometers (Corson et al. 1999). Relative forage quality (RFQ) was determined using the following equation (Undersander and Moore 2002):

$$\text{RFQ} = \text{DMI} \times \text{TDN}/1.23 \qquad [2]$$

where DMI = dry matter intake as a percentage of body weight, and TDN = total digestible nutrients as a percentage of dry biomass.

**Statistical Analysis.** Repeated measures analysis of variance (ANOVA) was used to determine the effect of simulated grazing treatments and time on the weed population density for each species and for the sum of all planted weed species using the PROC MIXED procedure with site and blocks within sites as random effects (SAS, SAS Institute, Inc. 100 SAS Campus Drive, Cary, NC 27513). All other variables (iPAR in April, iPAR in May, total biomass yield and RFQ at each simulated grazing event, total biomass yield summed over the experiment) were not compared over time but analyzed separately with ANOVA by using the Proc MIXED procedure and random effects. Homogeneity and normality were checked prior to analysis, and data were square root transformed to meet these requirements if necessary. For clarity, all data are presented untransformed. Fisher's LSD at $P \leq 0.05$ was used to separate the Least Square Means as appropriate. Linear least squares regression analysis was also utilized to compare the interaction between burdock, plumeless thistle, Canada thistle, and summed planted weed population densities with April iPAR. Significance of slopes from 0 were tested using an *F*-test and considered different at P values $\leq 0.05$.



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Table 1. Weed population density in May and September 2009 combined across locations and simulated grazing treatments at Arlington and New Glarus, WI. Values are the mean weed density at each date across five grazing treatments ($N = 40$).

| Date | Burdock[a] | Canada thistle | Plumeless thistle | Total |
|---|---|---|---|---|
| | plants $m^{-2}$ | | | |
| May | 4.3 a | 3.3 a | 1.5 a | 9.0 a |
| September | 1.5 b | 0.6 b | 0.4 b | 2.5 b |
| P value | < 0.01 | < 0.01 | 0.01 | < 0.01 |

[a] Means within a column followed by the same letter are not different according to Fisher's LSD at $P \leq 0.05$.

## Results and Discussion

**Weed Density.** Weed population densities of all species differed by sample date (Table 1) and all but plumeless thistle differed by treatment (Table 2), but no interaction between date and treatment was detected for any species or the sum of all weed species added to plots (data not shown). Weed population density decreased from May to September. While differences varied among species, densities were reduced 65 to 78% over the 3-mo period, regardless of treatment (Table 1). This indicates that by September, forage grasses were outcompeting many of the weeds that emerged in May. Others have observed similar results in grazed pastures (Grace et al. 2002; Wardle et al. 1995).

Increasing residual grass height at simulated grazing events reduced the population density of burdock and Canada thistle. Treatments that left at least 15 cm of residual grass had fewer burdock and Canada thistle plants than areas clipped to 10 cm, while treatments clipped to 5 cm only differed with burdock clipped to 20 cm (Table 2). Lack of differences with the 5-cm residual height may have been influenced by the simulated grazing as significant injury of seedling weeds were observed when clipped to 5 cm. This trend may be an artifact of mowing. If livestock are used to implement grazing treatments, weed seedling injury may not occur because animals tend to avoid weed species (Hein and Miller 1992; Liebman et al. 2001; Taylor et al. 2008). A similar response is seen when population densities of all weed species planted are summed (Table 2). These results are similar to those found in other studies that documented reduced emergence of musk and bull thistle seedlings in response to increased canopies of forages (Wardle et al. 1992). Plumeless thistle seedling population density did not decrease with increased forage canopy height. This may be due to its ability to germinate in low light intensities (Feldman et al. 1994). This, in combination with the repeated disturbances from MiRG that resulted in increased light penetration to the soil surface, may have allowed plumeless thistle to survive the higher residual heights. Alternatively, plumeless thistle density was low compared with the other two species evaluated and this may have prevented the detection of differences between treatments.

Table 2. Weed population density in 2009 as a result of simulated grazing treatments combined across locations and dates (May and September) at Arlington and New Glarus, WI. Values are the mean weed density from simulated grazing treatments ($N = 16$).

| Simulated grazing height | Burdock[a] | Canada thistle | Plumeless thistle | Total |
|---|---|---|---|---|
| | plants $m^{-2}$ | | | |
| 5 cm | 3.3 ab | 2.3 ab | 1.3 | 6.8 b |
| 10 cm | 5.3 a | 3.6 a | 1.5 | 10.4 a |
| 15 cm | 1.8 bc | 1.6 b | 1.2 | 4.6 b |
| 20 cm | 1.8 c | 1.0 b | 0.5 | 3.3 b |
| Not clipped | 2.3 abc | 1.1 b | 0.3 | 3.7 b |
| P value | 0.04 | 0.05 | NS[b] | < 0.01 |

[a] Means within a column followed by the same letter are not different according to Fisher's LSD at $P \leq 0.05$.
[b] Abbreviation: NS = not significant.

Table 3. Intercepted photosynthetically active radiation (iPAR) at the soil surface in spring 2009 as a result of simulated grazing treatments in fall 2008 combined across locations at Arlington and New Glarus, WI. Values are the mean iPAR from simulated grazing treatments ($N = 8$).

| Simulated grazing height | April[a,b] | May[c] |
|---|---|---|
| | iPAR | |
| 5 cm | 28 c | 62 |
| 10 cm | 48 b | 62 |
| 15 cm | 77 a | 66 |
| 20 cm | 77 a | 68 |
| Not clipped | 78 a | 66 |
| P value | 0.01 | NS[d] |

[a] Means within a column followed by the same letter are not different according to Fisher's LSD at $P \leq 0.05$.
[b] iPAR measurements taken on April 1, 2009, at both locations.
[c] iPAR measurements taken on May 15 and May 31, 2009, at New Glarus and Arlington, WI, respectively.
[d] Abbreviation: NS = not significant.

**iPAR and its Relationship with Weed Density.** In April, before grass or weed growth had begun, differences in iPAR were detected. Leaving 5 to 10 cm of residual forage the previous fall resulted in 38 to 64% less light intercepted by forages early the following spring compared with the 15-cm, 20-cm, and not clipped treatments (Table 3). Forages in areas with decreased light interception (5 and 10 cm) quickly grew and by the first grazing event in May, no differences in iPAR among simulated residual grazing heights were observed. Thus, light interception in the spring when common pasture weeds typically germinate in Wisconsin can be altered by changing fall grazing heights.

While iPAR differed among specific simulated grazing heights, results varied substantially within treatments. For instance, the 10-cm treatment had iPAR values ranging from 33 to 66% and summed population densities for planted weeds ranged from 8 to 22 plants $m^{-2}$ in May (data not shown). To determine the importance of light interception in the spring on weed emergence, we quantified the relationship between May individual and summed population densities for planted weeds with April

Table 4. Signifigance of slope from linear regression of intercepted photosynthetically active radiation (iPAR) at the soil surface in April and May weed population density combined across locations at Arlington and New Glarus, WI, 2009.

| Weed species | $F$ | P value | Equation[a] | $r^2$[b] |
|---|---|---|---|---|
| Burdock | 6.82 | 0.01 | $y = -0.10x + 11.47$ | 0.15 |
| Plumeless thistle | 0.20 | NS[c] | — | — |
| Canada thistle | 0.38 | NS | — | — |
| Sum of all planted weed species | 5.00 | 0.03 | $y = -0.11x + 15.01$ | 0.11 |

[a] $x$ and $y$ are iPAR in April and May weed population density, respectively, from the linear regression on weed species or the sum of all planted weed species.
[b] $r^2$ is the resulting correlation coefficient from the linear regression.
[c] Abbreviation: NS = not significant.



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Table 5. Total biomass yield from simulated grazing in 2008 to 2009 combined across both locations at Arlington and New Glarus, WI. Values are the mean biomass from simulated grazing treatments ($N$ = 8).

| Simulated grazing height | Fall graze[a] | 1st graze | 2nd graze | 3rd graze | 4th graze | Total |
|---|---|---|---|---|---|---|
| | g m$^{-2}$ | | | | | |
| 5 cm | 206 a | 109 a | 80 | 50 | 53 | 490 a |
| 10 cm | 87 b | 66 b | 66 | 46 | 38 | 298 b |
| 15 cm | 38 c | 42 bc | 77 | 54 | 45 | 239 bc |
| 20 cm | 11 c | 31 c | 73 | 53 | 44 | 194 c |
| P value | < 0.01 | < 0.01 | NS[b] | NS | NS | < 0.01 |

[a] Means within a column followed by the same letter are not different according to Fisher's LSD at P ≤ 0.05.
[b] NS = not significant.

iPAR, regardless of treatments. A significant negative relationship between April iPAR and burdock and summed population densities for planted weeds was observed (Table 4). We found that when 28% of the light is intercepted (typical for the 5-cm residual height), 12 weeds m$^{-2}$ were predicted, while increasing the light intercepted to 77% (typical for the 15-cm residual height) decreased weed density to 7 plants m$^{-2}$, a 45% reduction. Additional reductions in weed density would be expected throughout the summer (72% reduction in summed population densities for planted weeds from May to September was observed; Table 1), further reducing the predicted weed species population density to 2 plants m$^{-2}$. Similar reductions in weed population density from this type of management have been seen in other crops. For example, wheat increased light interception and decreased emergence of plumeless thistle seedlings 70% (Kruk et al. 2006). While the relationship between April iPAR and burdock and summed population densities for planted weeds were significant, the relationship was not highly correlated (for burdock, $r^2$ = 0.15; for summed population densities for planted weeds, $r^2$ = 0.11) (Table 4). This suggests that other factors in addition to early season light interception are involved in the observed reduction in weed population densities. Others have found changing grazing heights causes differences in soil moisture, nutrient availability, and belowground competition for limiting resources (Jutila and Grace 2002; Weiner et al. 1997). Future work is needed to determine the specific mechanism(s) responsible for reduced emergence, but it appears that light interception in the spring when weeds are germinating may be one mechanism.

**Total Biomass Yield.** The 5-cm treatments resulted in 64 to 253% more total biomass yield (including weed biomass) than other simulated grazing heights, but differences in biomass were attributed to differences that occurred in the fall and first spring grazing events (Table 5). In the fall the 5-cm cutting height had the greatest yield with reductions between 58 and 95% observed with higher cutting heights (Table 5). Leaving 10 cm of forage resulted in lower forage yields in the fall than the 5-cm treatment, but a 10-cm residual height still produced two to eight times more forage than the 15- and 20-cm cutting heights (Table 5). The 5-cm treatment also resulted in higher forage yield than other treatments in the first spring grazing event in May 2009, with treatments clipped to 10, 15, or 20 cm resulting in 39 to 72% lower forage yields. Similar to the fall results, the yield of the 10-cm residual height was intermediate, with higher yields than the 20-cm treatment. In the summer (second to fourth simulated grazing events), no differences in forage yield were seen among treatments at either site. These data are consistent with results from Inyang et al. (2010) and Bryan et al. (2000) who demonstrated pasture grasses grazed or clipped to shorter heights had 21 and 18% higher yield throughout the season when managed for taller residual heights. While the highest overall yield would result from grazing to 5 cm, typical MiRG grazing heights recommended are 10 cm (Undersander et al. 2002). Our data indicate that increasing the grazing height from 10 to 15 cm to improve weed suppression would not result in a decrease in total biomass yield throughout the grazing season, but less would be available in the fall grazing if managed to 5 cm (Table 5).

Table 6. Relative forage quality (RFQ) of forage biomass at simulated spring grazing in 2009 combined across both locations at Arlington and New Glarus, WI. Values are the mean biomass from simulated grazing treatments ($N$ = 8).

| Simulated grazing height | 1st graze[a] | 2nd graze | 3rd graze | 4th graze |
|---|---|---|---|---|
| | Relative forage quality | | | |
| 5 cm | 129 | 146 | 138 a | 114 |
| 10 cm | 136 | 147 | 135 a | 116 |
| 15 cm | 139 | 145 | 125 b | 111 |
| 20 cm | 143 | 142 | 120 b | 108 |
| P value | NS[b] | NS | <0.01 | NS |

[a] Means within a column followed by the same letter are not different according to Fisher's LSD at P ≤ 0.05.
[b] NS = not significant.

**Forage Quality.** Desired RFQ values are reported to be from 120 for a cow-calf pair to 150 for a lactating dairy cow (Undersander et al. 2002). Across simulated grazing heights, RFQ remained above the threshold for cow–calf pairs during the spring and summer except for the last grazing event. However, RFQ never met the required threshold for lactating dairy cows regardless of forage height management. Differences in RFQ were only detected among treatments at the third grazing interval where forage quality of the 15- and 20-cm treatments were lower than the 5- and 10-cm treatments (Table 6). We believe lower simulated grazing heights (5 and 10 cm) induced the grass to tiller resulting in higher RFQ values. Others have observed low grazing to promote new leaf growth (Cullen et al. 2006) that has higher RFQ values (Undersander et al. 2002). The lower RFQ values of the 15- and 20-cm grazing treatments at the third harvest were likely a result of increased stem tissue, which is known to decrease RFQ (Karn et al. 2006).

Our data demonstrates retaining 15 to 20 cm of residual height in the fall and through the following grazing season can decrease burdock and Canada thistle establishment



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from seed 56 to 72% compared with typical residual heights (10 cm). Increased light interception in the early spring (April) from higher residual grazing heights was correlated with observed suppression of burdock and could be one of the mechanisms involved in this suppression. Increasing the grazing height from 5 or 10 cm to 20 cm reduced total biomass yield and forage quality. However, yield and quality losses were not consistent throughout the year with yield reductions confined to the fall and the first spring, and forage quality in a midsummer grazing event. Leaving 15 cm of residual height reduced some, but not all of the forage loss associated with taller forage management, while still providing increased weed suppression compared to managing shorter than 15 cm. More research should be conducted to determine how consistent this observed result is with other weed species and when utilizing livestock to implement treatments. Livestock may preferentially avoid or feed on weeds altering results compared to simulated grazing, and the disturbance from hoof action could also be an important factor. Additionally, an evaluation of when the grazing height should be increased throughout the season is needed, as our results suggest that maintaining fall residual heights greater than 10 cm are important in reducing weed density the following spring. If residual heights at other grazing intervals could be maintained at 5 to 10 cm, while still providing adequate weed suppression, the additional forage available for animals may increase the adoption of this practice.

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