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Persistence of various alfalfa populations in South Dakota rangeland[1]

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SUMMARY

Inclusion of alfalfa (*Medicago sativa* L.) in grasslands has long been valued to increase forage production and quality. Persistence of alfalfa in semiarid rangeland has generally been poor when non-adapted and/or conventional hay-type cultivars are utilized, however. Demand exists for alfalfa cultivars that establish readily and persist, particularly under grazing, in semiarid rangelands. A wild population of predominantly yellow-flowered alfalfa (*Medicago sativa* subsp. *falcata*) was found growing and reproducing naturally in the Grand River National Grassland in northwestern South Dakota. This predominantly *falcata* alfalfa therefore demonstrates persistence in this semiarid environment. We initiated a study in May 2006 at the SDSU Antelope Livestock & Range Field Station near Buffalo, SD to evaluate persistence and vigor of eleven alfalfa populations transplanted into mixed-grass prairie. Populations consisted of four predominantly *falcata* experimental populations (three are naturally selected and locally adapted; one is artificially selected), one pure *falcata* experimental population, one pure *falcata* cultivar, two pasture-type cultivars, and three conventional hay-type cultivars. Greenhouse-grown seedlings were transplanted on 1 m-centers within three exclosures (35 m X 35 m) divided into two sections; one exposed to grazing, the other protected from grazing. Grazing by cattle was initiated in August 2007. During the 2008 and 2009 growing seasons, intense grazing of alfalfa plants and associated vegetation occurred monthly for 1-2 days. Survival, height, and canopy volume of grazed and protected alfalfa plants were measured before each grazing event. Despite a harsh winter with persistent ice cover, data from May 2009 revealed that *falcata*-based populations had the highest survival under grazing (mean survival = 36%). Pasture-type cultivars and conventional hay-type cultivars experienced substantial mortality losses under grazing (mean survival = 8%). Low mortality and high vigor of all protected plant populations indicates that grazing weakened the grazed plants, greatly increasing the risk of winterkill and winter injury. These findings reveal that environmental adaptation, in addition to a degree of grazing tolerance, is necessary for persistence under grazing in this semiarid region. Populations that exhibit high persistence under both grazing and severe winter conditions offer great potential for being utilized in the northern Great Plains.

INTRODUCTION

Alfalfa has long been valued for increasing forage production and quality of grasslands in the northern Great Plains region of North America. In a review of numerous studies, Popp et al. (2000) noted that livestock production is increased when alfalfa is introduced into grass-dominated swards. However,

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alfalfa persistence in semiarid regions is generally poor, particularly under grazing. Reasons for this include utilizing cultivars that do not persist under grazing (Smith et al., 2000) or are not adapted to the regional environment (Ries, 1982). The ability to survive climatic extremes such as severe winters is necessary when alfalfa is used for grazing in northern climates (Hendrickson and Berdahl, 2003).

A naturalized population of predominantly yellow-flowered alfalfa (hereafter referred to as *falcata*) found growing on private and public rangeland in northwestern South Dakota may provide sustainable benefits to this region (Xu et al., 2004). This population, which originated in Siberia, was introduced to settlers in this region during the early 1900's by Professor N. E. Hansen (Smith, 1997). Persistence, high forage production, and natural reseeding are positive attributes of this *falcata*-based alfalfa (Smith, 1997). Studies have also revealed this alfalfa has increased carbon and nitrogen levels in rangeland soils of the Great Plains (Mortenson et al., 2004) and provides wildlife habitat (Boe et al., 1998).

The adaptability of this naturalized population of *falcata*-based alfalfa in comparison to other alfalfa populations/cultivars has not been studied previously. Adaptation of alfalfa to climate and grazing is important within the northern Great Plains, especially when the intended use will be for grazing. Grazing alfalfa plants causes stress resulting from defoliation, tugging/tearing, trampling, and defecation (Smith et al., 2000). These stresses are not encountered if plants are not grazed.

The objective of this study was to determine the suitability of *falcata*-based alfalfa populations for use as a pasture species in the Northern Great Plains. We hypothesize that locally adapted, naturally-selected alfalfas will exhibit greater persistence than other populations.

METHODS

Study Site

The study was conducted at the SDSU Antelope Livestock & Range Field Station near Buffalo, SD (45.57° N latitude, 103.53° W longitude). The climate is continental and semiarid. Monthly mean maximum temperature is 30.2^{o}C in July, and the monthly mean minimum temperature is -15.7^{o}C in January (HPRCC, 2010). Mean annual precipitation is 344 mm, with approximately 70% of the precipitation occurring from April through August (HPRCC, 2010).

Soils of the experimental sites are located on Rhoades-Daglum loams. The Rhoades series are fine, smectitic, frigid Leptic Vertic Natrustolls while the Daglum series are fine, smectitic, frigid Vertic Natrustolls. Both soils are identical except the Rhoades series has thinner soil horizons.

Mixed grass prairie is the native vegetation type of this region. Dominant grass species include western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Löve], green needlegrass [*Nassella viridula* (Trin.) Barkworth], blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths], and buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus]. A variety of forbs are present, and some areas have considerable amounts of silver sagebrush (*Artemisia cana* Pursh) and big sagebrush (*Artemisia tridentata* Nutt).

Materials

During the spring of 2006, seeds of eleven alfalfa populations (Table 1) were germinated in the greenhouse in plastic cone-containers. Alfalfa seedlings were transplanted on 1-m centers within three exclosures (35 m X 35 m) of mixed grass prairie on May 22-23, 2006. After transplanting, the seedlings were watered three times within a period of three weeks to ensure survival.

Table 1. Eleven alfalfa populations evaluated at the SDSU[1] Antelope Livestock & Range Field Station

Population	Functional Group/Description
Pioneer 5454	Conventional hay-type cultivar
Garst 6200HT	Conventional hay-type cultivar
Vernal	Conventional hay-type cultivar
Don	Pure *falcata* cultivar from USDA-ARS, Logan, UT
SD201	Pure *falcata* experimental for forage and wildlife habitat
SD Coiled	Predominantly *falcata* SDSU experimental from feral rangeland population in northwestern South Dakota
SD Sickle	Predominantly *falcata* SDSU experimental from feral rangeland population in northwestern South Dakota
Falcata	Predominantly *falcata* alfalfa developed by N. Smith, Lodgepole, SD
Mandan A9191	Predominantly *falcata* experimental from USDA-ARS, Mandan, ND
Alfagraze	Pasture-type cultivar
Travois	Pasture-type cultivar

[1]SDSU = South Dakota State University

Experimental Design

The experimental design for this study was a nested and crossed factorial design. The eleven populations were crossed with the three exclosures. Eight replicates were nested within each exclosure. The eleven alfalfa populations were randomly assigned within each replicate. One replicate of a population contained seven transplants. Within an exclosure, six replicates of a population were subjected to livestock grazing, whereas two replicates were protected from livestock grazing. Protection excluded livestock defoliation and trampling, but did not exclude possible wildlife activity.

Alfalfa plants were mob-grazed as described by Bittman and McCartney (1994). All alfalfa populations were uniformly grazed by beef cows (*Bos taurus*), cow-calf pairs or yearling heifers for 1 to 2 days. The livestock class used was dependent on animal availability at the time. Stocking was determined based on the need to intensely defoliate the plants in a relatively short period of time. Rest periods between grazing events during the growing season ranged from 22 to 41 days. Grazing was initiated in August 2007. Populations were grazed four times during the 2008 growing season and three times during the 2009 growing season. In 2008, the last grazing period occurred on August 20. Due to dry conditions in 2009, the last grazing period occurred on August 4.

Measurements occurred shortly before each grazing event in 2008, but did not coincide with grazing events in 2009. For both grazed and protected plants, survival (presence or absence), plant height, and canopy volume measurements were obtained. Canopy volume is an indicator of plant vigor. Canopy data were collected in the field by measuring the longest diameter of the canopy (A) and then measuring the diameter perpendicular to it (B). Using height data with diameter data, canopy volume was calculated using the following ellipsoid volume formula as provided by Thorne et al. (2002):

$$[2/3 * \pi * \text{Height} * (\text{Diameter A}/2 * \text{Diameter B}/2)]$$

Statistical Analyses

Canopy volume data from the 2009 field season was unbalanced because of variability in plant survival between populations subjected to grazing. Sample size for some alfalfa populations was too small to effectively calculate a sample mean representative of the population. Merging and analyzing the population data as functional groups increased the strength of the analysis, however. This allowed effective mean separation. Some statistical results are therefore presented as functional groups.

Population entries and functional groups were treated as fixed factors, whereas replicates and exclosures were treated as random factors. Consideration of exclosure as a random factor allows inferences to be made to the regional landscape.

Survival data were analyzed using PROC FREQ (SAS Inst. Inc., Cary, NC). Canopy volume data for functional groups were analyzed using PROC MIXED. A two sample t-test using PROC TTEST was conducted to detect differences in canopy volume between grazed and protected environments within functional groups. Differences between population entries, functional groups, and protected vs. grazed plants within functional groups were considered significant at $P \leq 0.05$.

RESULTS AND DISCUSSION

Weather

Temperatures for the 2009 growing season were 1.4°C cooler than the 57-year average and precipitation was below normal (Table 2). The growing season of 2008 was considerably wetter than 2009, particularly during May and June.

Table 2. Average monthly precipitation (mm) and temperature (°C) for the SDSU Antelope Livestock & Range Field Station for the growing seasons of 2008 and 2009 and the 57-year average (1951-2008)

Month	2008[1]	2009[1]	Average[2]
	Precipitation		
	---------- mm ----------		
April	19	16	26
May	101	28	59
June	93	40	65
July	34	80	59
August	34	34	38
	Monthly Mean Temperature		
	---------- °C ----------		
April	5	4	6
May	10	12	11
June	16	16	17
July	22	19	22
August	21	19	21

[1] Antelope Research Station Automatic Weather Data Network 2009.
[2] High Plains Regional Climate Center 2010.

For the months of April, May, and June in 2009, precipitation was 66 mm below the 57-year average. Despite one heavy rainfall event (58 mm) that occurred on July 3, 2009, all other rainfall events that occurred during the growing season were less than 17 mm.

Survival

Persistence (long-term survival) is an essential trait of any alfalfa crop growing in a semiarid climate. Forage production is secondary to persistence since high forage production is meaningless if survival is uncertain, particularly under grazing. Good persistence is essential for pasture improvement, particularly to minimize time and cost if alfalfa is interseeded into a grass stand.

Plant survival at the end of May 2009 revealed differences in survival among the eleven alfalfa populations for both grazed and protected plants. As long as all plants have broken dormancy, mid-late May appears to be the best time to obtain reliable winter survival data.

Falcata-based populations showed the greatest survival under grazing in May 2009 (Figure 1). In particular, SD Sickle and Don had the highest survival.

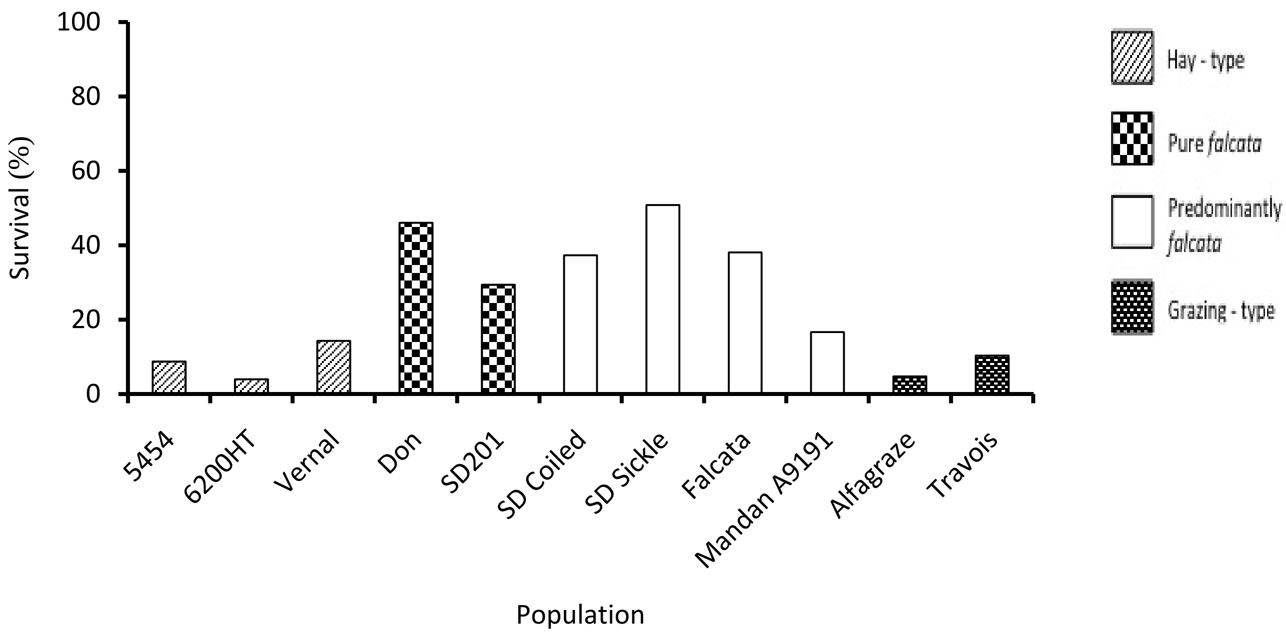

Figure 1. Survival of eleven grazed alfalfa populations (combined over three exclosures) in May 2009 ($P < 0.0001$) at the SDSU Antelope Livestock & Range Field Station. Survival was based on 126 original transplants per population.

Protected alfalfa plant survival also revealed differences between populations (Figure 2). However, survival differences were not as pronounced as for the grazed plants. With the exception of 5454 and 6200HT, all other populations had similar survival (57% – 76%). This would be expected since the protected plants were subjected to less stress than the grazed plants. Vernal, a hay-type cultivar developed in the 1950s, actually had the greatest survival.

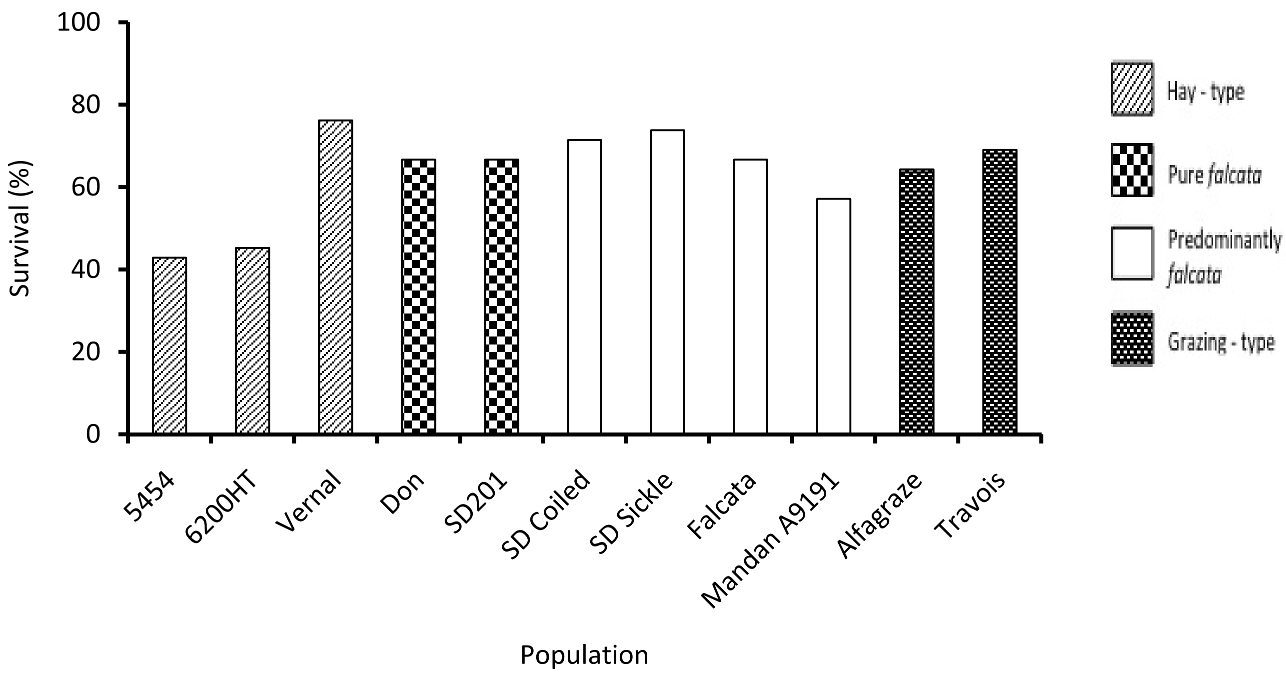

Figure 2. Survival of eleven protected alfalfa populations (combined over three exclosures) in May 2009 (P = 0.0171) at the SDSU Antelope Livestock & Range Field Station. Survival was based on 42 original transplants per population.

Substantial winterkill of grazed alfalfa plants occurred during the 2008 – 2009 winter. Weather accounts provide evidence of the harsh conditions that were encountered (D. Young, personal communication). Snowfall received in November 2008 melted but then froze, resulting in a layer of ice over the entire landscape. Wet snow continued to accumulate on top of this ice during the winter, becoming hard as it aged. This layer of ice on the ground surface therefore persisted throughout most of the winter until March 2009. The alfalfa plants were under a layer of ice for about four months during this winter.

Mortality of grazed plants from July 2008 to May 2009 is depicted in Figure 3. Large reductions in survival occurred during this time period for many of the alfalfa populations. Most of the losses can be attributed to winterkill. *Falcata*-based populations tended to have less severe losses. Winter loss is based on plants present in July 2008, not the plants transplanted in May 2006, removing effects of factors that contributed to losses before July 2008.

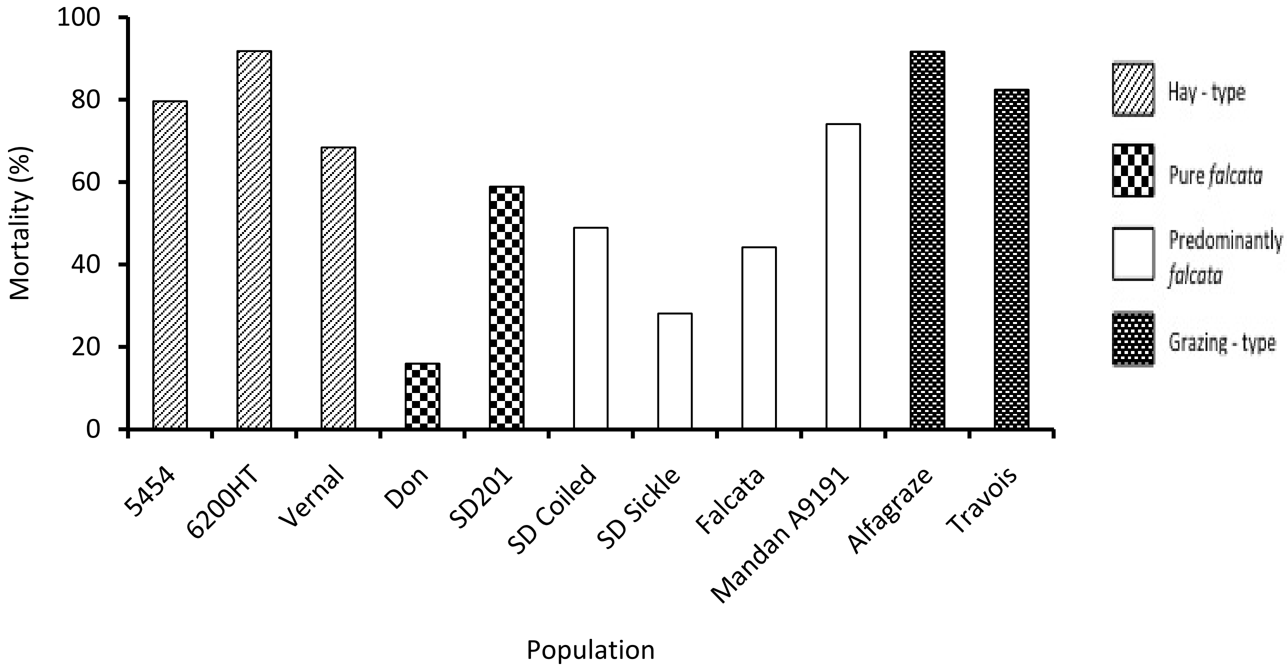

Figure 3. Percent mortality of grazed plants from July 2008 to May 2009 at the SDSU Antelope Livestock & Range Field Station. Percentages are based on the total number of plants present in July 2008 (n = 825).

Mortality was less for protected plants than for grazed plants. From July 2008 to May 2009, mean mortality was 8% for plants that were not subjected to livestock grazing. Only 6200HT, Mandan A9191, and Alfagraze had mortality losses greater than 10%.

Interacting factors make determining the exact cause of mortality difficult. The climatic conditions that resulted in ice build-up may have caused winterkill of grazed plants due to anoxia (lack of oxygen). Differences between populations may also exist in the ability to survive ice encasement. However, factors other than persistent ice sheeting contributed to this loss, since the protected plants did not experience the losses that grazed plants did.

Compared to continuous grazing, the mob grazing used in this study would be considered less damaging to alfalfa plants. Replenishment of carbohydrate reserves would be expected to occur when alfalfa plants are given 22 – 41 days of rest between 1-2 day grazing periods. However, high frequency hay cutting has been known to deplete alfalfa stands. Alfalfa may be cut before reserves have been adequately replenished under these high frequency hay cutting regimes. Our grazing protocol mimics a high frequency hay cutting regime for dryland alfalfa in western South Dakota (3 to 4 cuts per growing season). Additionally, giving alfalfa plants a long rest period does not insure adequate regrowth or replenishment of reserves if growing conditions are poor before the next grazing period (i.e. dry conditions). We believe that many of the grazed plants entered the 2008-2009 winter with inadequate reserves, since many of the plants attempted to regrow in early fall. Poor regrowth during this critical time period may not have allowed adequate replenishment of reserves before the first killing frost.

Based on these observations, we speculate grazing may have indirectly contributed to winterkill by weakening the plants to some degree. Grazing also reduced vegetative ground cover and standing stubble, which are both necessary for crown protection. Protected plants had considerable amounts of standing stubble going into the winter. However, environmental adaptation is also necessary for survival under grazing. Alfagraze, which was developed under continuous grazing in Georgia, has very poor survival under mob grazing in this semiarid environment. Grazing tolerance may therefore not confer high persistence if the cultivar is not adapted to the regional environment.

Fall dormancy (or degree of autumn growth) has generally been used as a predictor of alfalfa winter hardiness. Fall dormancy scores range from 1 to 9. Cultivars with low fall dormancy scores (1 to 2) are considered to be very winter hardy and exhibit little fall growth compared to non dormant cultivars. One issue is that the experimental populations in this study do not have fall dormancy scores assigned to them. However, these populations could be classified as dormant alfalfas due to their relatively good survival after the winter of 2008-2009. Cultivars in this study do have fall dormancy scores (Table 3).

Table 3. Fall dormancy scores for cultivars evaluated in the study

Cultivar	Fall Dormancy Score
Don	1
Travois	1
Vernal	2
Alfagraze	2
6200HT	2
5454	4

Don has very high dormancy, and this may have contributed to winter survival. Observations on September 18, 2008 revealed that many grazed plants of Don were not present. However, plant presence for Don was greater in May 2009, indicating that a large number of plants not present in September 2008 were dormant, not dead.

Alfalfa survival partly depends on stresses that plants are exposed to. Although protected plants were defoliated by wildlife, most of this left residual plant material. Grazed plants were exposed to mob grazing by cattle, where the majority of leaf and stem material was removed by heavy defoliation. Associated palatable vegetation (i.e. grasses) was also grazed short. As a result, protected plants and grazed plants entered the winter of 2008-2009 in differing physiological condition. Persistent winter ice cover demonstrated that mob grazing added additional stress. Differences in survival under grazing between populations are most likely due to differences in adaptation, intended use (haying vs. grazing), and tolerance to grazing. Reductions in ground cover and standing stubble resulting from grazing also may have limited survival, however.

Canopy Volume

Canopy volume provided a measure of growth (or vigor) of the alfalfa plants in this study. For all three sampling periods in 2009, no differences in canopy volume between functional groups of grazed plants were detected. Relatively dry conditions during the growing season resulted in little regrowth after each grazing event. Protected plant canopy volumes are not presented because of substantial wildlife defoliation in two exclosures. It is also likely that grazed plants were also defoliated by wildlife during the growing season as well.

Mean canopy volume comparisons of grazed and protected plants within functional groups in late May 2009, before any grazing, provide evidence of winter injury. Surviving plants, exposed to grazing during 2008, expressed less vigorous spring growth compared to protected plants within the same functional group (Figure 4).

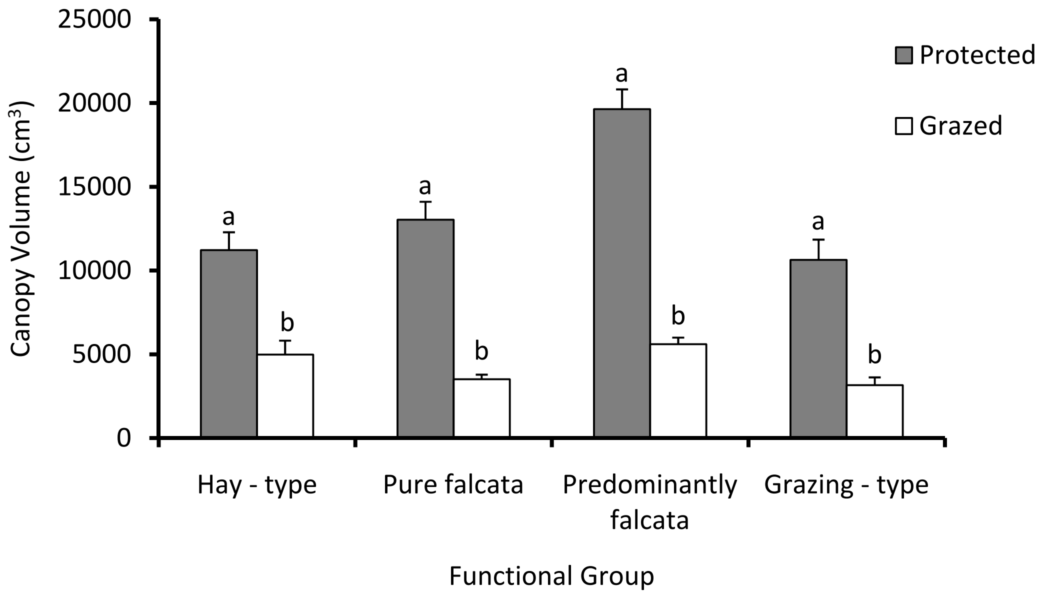

Figure 4. Spring canopy volume (cm^3) of protected and grazed functional groups on May 27, 2009 before the first grazing event of the growing season. Means within a functional group with different letters are different ($P \leq 0.05$).

Differences in canopy volume during May, between protected and grazed plants within the same functional group, were detected ($P \leq 0.05$). Observations in early May revealed that protected plants were beginning to green up (break dormancy) but grazed plants were not growing. Alfalfa plants that are weak and slow to green up in spring indicate winter injury.

Management was not implemented to allow the grazed plants to recover after the severe winter. Deferring grazing or cutting of alfalfa until later maturity stages (such as early-bloom or later) is commonly recommended. This would allow plants to restore carbohydrate reserves and vigor. In this study, the first grazing on May 29, 2009 occurred when weak plants were still small and vegetative. Due to three grazing events and dry conditions in 2009, it is possible that full recovery of grazed alfalfa plants did not occur.

CONCLUSIONS

Locally adapted alfalfa populations that have a high percentage of *falcata* background exhibited greater survival under grazing than non-adapted populations. Adaptation to the regional environmental conditions allowed these populations to be persistent despite stressful conditions.

Grazing alfalfa plants during the growing season in 2008 most likely contributed to alfalfa winterkill and winter injury. Subsequent grazing events during 2009 after a severe winter, in combination with dry summer conditions, most likely did not allow substantial recovery to occur. Continued alfalfa persistence will depend on the ability of these plants to endure additional stress.

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