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Stand Persistence and Forage Yield of 11 Alfalfa (*Medicago sativa*) Populations in Semiarid Rangeland☆,☆☆

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ABSTRACT

Livestock producers in the Northern Great Plains value alfalfa (*Medicago sativa* L.) for increasing forage production and quality in grazing lands. However, alfalfa persistence can be poor, especially under grazing. Demand exists for alfalfa that can establish and persist in semiarid grazing lands. A naturalized population of predominantly yellow-flowered alfalfa (*Medicago sativa* L. subsp. *falcata* [L.] Arcang.) was found growing and reseeding on private and public rangeland in northwestern South Dakota. This naturalized alfalfa population demonstrates persistence in this semiarid environment. A study, initiated in May 2006 at the Antelope Range and Livestock Research Station near Buffalo, South Dakota, evaluated stand persistence and forage yield of 11 alfalfa populations transplanted into mixed-grass prairie. Populations were pure *falcata*, predominantly *falcata*, hay-type *sativa*, or pasture-type *sativa* populations. Transplants were space planted on 1-m centers within three exclosures (35 × 35 m) divided into two sections, which were either mob grazed by cattle or protected from mob grazing. Mob grazing began in August 2007 and continued periodically through 2008 and 2009. Survival, plant height, plant canopy diameters, and biomass data were collected. Grazing, dry spells, and ice sheets subjected alfalfa plants to substantial stress. High mortality of grazed plants occurred during the 2008–2009 winter. Hay-type *sativa* and pasture-type *sativa* populations exposed to mob grazing had poor final survival (<19%) and forage yield in July 2010. However, pure *falcata* and most predominantly *falcata* populations had higher survival (>38%) and forage yield. Low mortality and high yield of protected plants indicated that accumulated stress from mob grazing weakened grazed plants, increasing environment-related mortality (e.g., winterkilling). *Falcata*-based populations persistent under mob grazing and adapted to the regional environment have potential for use in the Northern Great Plains.

Introduction

Livestock producers in the Northern Great Plains value alfalfa (*Medicago sativa* L.) in grass stands for increasing forage production and quality. Popp et al. (2000) noted that livestock production is increased when alfalfa is introduced into grass-dominated swards. However, continued and reliable forage production is a problem for producers utilizing alfalfa for grazing in semiarid regions (Lorenz et al., 1982) because stand persistence can be poor (Campbell, 1963; Bliss, 2003). Poor stand persistence is the result of poor grazing tolerance (Smith et al., 2000) and/or poor adaptation 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 the Northern Great Plains (Hendrickson and Berdahl, 2003).

A naturalized population of predominantly yellow-flowered alfalfa (*Medicago sativa* L. subsp. *falcata* [L.] Arcang.; hereafter referred to as *falcata*) originating from Siberia and found growing on private and public rangeland in northwestern South Dakota may provide beneficial traits for alfalfa in this region (Smith, 1997; Xu et al., 2004). Persistence, high-forage production, and natural reseeding are positive characteristics of this population (Smith,

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1997). In addition, *falcata*-based alfalfa has shown to increase carbon and nitrogen levels in rangeland soils (Mortenson et al., 2004) and may enhance wildlife habitat (Boe et al., 1998).

Multiple factors affect alfalfa persistence in semiarid regions. Environmental factors, use, management, and population (cultivar or strain) affect persistence. Several alfalfa populations have been evaluated under rangeland conditions and management (e.g., grazing and/or cutting) in the Northern Great Plains. Survival of alfalfa is affected by grazing due to stresses resulting from defoliation, tugging/tearing, trampling, and defecation (Smith et al., 2000). Previous studies (Berdahl et al., 1986, 1989; Hendrickson and Berdahl, 2003) demonstrated that hay-type populations or populations adapted to milder climates persist poorly under grazing in semiarid rangelands.

Persistence and performance of *falcata*-based alfalfa populations in comparison with other alfalfa cultivars/strains in the Northern Great Plains have been studied previously (Berdahl et al., 1986, 1989; Hendrickson and Berdahl, 2003). However, not all *falcata*-based populations perform the same and this may be the case even if populations have similar origins. The current study in northwestern South Dakota evaluates *falcata*-based populations that have not been evaluated previously. The objective of this study was to determine the suitability of these *falcata*-based alfalfa populations for grazing use in the Northern Great Plains. We hypothesize that locally adapted, naturally selected *falcata*-based alfalfas will exhibit greater persistence and forage production than hay-type *sativa* and pasture-type *sativa* populations. In addition, we hypothesize that exposing alfalfa populations to livestock grazing will negatively affect persistence and yield compared with no livestock grazing.

Methods

Study Location and Description

Research was conducted at the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, SD, USA (lat 45°35 02 N, long 103°32 45 W). Environmental conditions for this semiarid area include a monthly mean maximum temperature of 29.4 °C in July and a monthly mean minimum temperature of −14.5 °C in January (HPRCC, 2010). Average annual precipitation (1971–2000) is 398 mm (Table 1), with 77% occurring from April through September (HPRCC, 2010).

Soils at the experimental site are Rhoades–Daglum loams. Rhoades soils are fine, montmorillonitic Leptic Natriborolls, while Daglum soils are fine, montmorillonitic Typic Natriborolls (USDA-SCS, 1988). Native vegetation for this region is mixed-grass prairie. Dominant grass species include western wheatgrass (*Pascopyrum smithii* [Rydb.] Á. 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 contain considerable big sagebrush (*Artemisia tridentata* Nutt.) and silver sagebrush (*Artemisia cana* Pursh).

Experimental Design

During the spring of 2006, seeds of 11 alfalfa populations (Table 2) were germinated in the greenhouse in 3.8 × 21 cm plastic cell containers (Ray Leach "Cone-tainers"; Stuewe & Sons, Inc, Tangent, OR). Each alfalfa population belonged to one of four functional groups: pure *falcata* ($n = 2$), predominantly *falcata* ($n = 4$), hay-type *sativa* ($n = 3$), or pasture-type *sativa* ($n = 2$). Functional group designations were based on intended use and phenotypic characteristics such as growth habit, flower color, and seed pod shape. Predominantly *falcata*

Table 1
Average monthly temperature (°C) and precipitation (mm) from January through December for 2006, 2007, 2008, 2009, 2010, and the 30-yr average (1971–2000) for the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, South Dakota.

Month	2006[1]	2007[1]	2008[1]	2009[1]	2010[1]	30-yr average[2]
	------------------------------Temperature (°C)------------------------------					
January	−0.2	−6.0	−9.2	−7.4	−9.8	−8.3
February	−4.7	−8.9	−7.7	−7.2	−11.8	−4.9
March	−0.8	3.9	−0.5	−4.3	0.5	−0.2
April	8.1	5.0	4.2	3.1	6.7	6.3
May	12.5	13.1	10.0	11.2	10.2	12.4
June	18.4	18.2	15.4	14.8	16.4	17.6
July	24.4	25.0	20.9	18.6	20.1	21.3
August	21.2	21.2	20.4	18.4	20.5	20.7
September	12.6	14.6	12.9	16.3	13.3	14.8
October	4.9	7.9	6.2	2.9	9.1	7.9
November	−0.5	−1.0	0.1	2.3	−3.1	−0.8
December	−5.0	−7.2	−10.9	−12.7	−10.9	−6.4
	-------------------------------Precipitation (mm)-------------------------------					
January	12	2	3	2	4	8
February	8	19	18	33	11	10
March	14	40	9	90	16	20
April	64	30	26	35	42	39
May	28	103	141	27	90	74
June	56	32	92	41	94	77
July	13	21	36	70	46	53
August	35	69	38	28	95	37
September	55	4	13	10	59	25
October	18	4	35	51	13	34
November	6	5	47	1	28	13
December	0	10	16	25	12	8
Total	309	339	474	413	510	398

[1] NOAA (On site weather station) (2010).
[2] HPRCC (Weather station is located 14.5 km northeast of Redig, SD) (2010).

populations have introgression of *sativa* germplasm. The degree of *sativa* introgression is unknown for SD 202, SD 203, and Falcata because hybridization happened naturally on rangeland. However, SD 203 probably has a higher percentage of *falcata* germplasm than SD 202 and Falcata based on phenotypic characteristics such as sickle-shaped seed pods.

SD 201, Falcata, SD 202, and SD 203 have origins that can be traced back to *falcata*-based sources from rangeland in central and western South Dakota. SD 201 is an experimental synthetic cultivar (Boe et al., 1998). Falcata originated from the N. G. Smith Ranch, where it has been propagated through the years by interseeding and conservative grazing, which allow the alfalfa to produce seed and reseed naturally (Smith, 1997). This alfalfa spread and became naturalized in the Grand River National Grassland, which is adjacent to the Smith Ranch (Xu et al., 2004). SD 202 and SD 203 were selected directly from this naturalized population source on the Grand River National Grassland and have not been further developed using artificial selection procedures. SD 202 and SD 203 are distinct from Falcata because these two populations are considered to be more naturalized (i.e., feral) and have not been intensively managed for seed production.

Alfalfa seedlings were space transplanted on 1-m centers within three exclosures (35 × 35 m) 22–23 May 2006. After transplanting, seedlings were watered three times within a period of 3 wk to improve survival. No livestock grazing of seedlings occurred during 2006 in order to encourage establishment.

Experimental design for this study was a nested and crossed factorial design. Eleven alfalfa populations were crossed with three exclosures. Eight replicates were nested within each exclosure. Eleven alfalfa populations were randomly assigned within each replicate. One replicate of a population contained seven transplants. Within an

Table 2
Functional group/description and fall dormancy score for 11 alfalfa populations evaluated at the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, South Dakota.

Population	Functional group/description	Dormancy[1]
Don	Pure *falcata* cultivar from USDA-ARS,[2] Logan, Utah	1[3]
SD 201	Pure *falcata* South Dakota State University experimental for forage and wildlife habitat	1[4]
SD 203	Predominantly *falcata* South Dakota State University experimental with sickle-shaped seed pods collected from a feral population in native rangeland in northwest South Dakota	1[4]
Falcata	Predominantly *falcata* alfalfa developed by Norman G. Smith, Lodgepole, South Dakota and supplied by Wind River Seed, Manderson, Wyoming	1[4]
SD 202	Predominantly *falcata* South Dakota State University experimental with coil-shaped seed pods collected from a feral population in native rangeland in northwest South Dakota	1[4]
Mandan A9191	Predominantly *falcata* experimental from USDA-ARS, Mandan, North Dakota	-
Vernal	Conventional hay-type *sativa* cultivar	2[5]
Pioneer 5454	Conventional hay-type *sativa* cultivar	4[5]
Garst 6200HT	Conventional hay-type *sativa* cultivar	2[5]
Travois	Pasture-type *sativa* cultivar	1[6]
Alfagraze	Pasture-type *sativa* cultivar	2[5]

[1] Lower scores indicate that the population is more dormant on the basis of the height of fall regrowth (Tueber et al., 1998).
[2] USDA-ARS, United States Department of Agriculture–Agricultural Research Service.
[3] Peel et al. (2009).
[4] A. Boe, personal communication, July 2014.
[5] National Alfalfa Alliance (2004).
[6] Hendrickson and Berdahl (2003).

exclosure, six replicates of a population were subjected to livestock grazing, whereas two replicates were protected from livestock grazing by erecting a fence within each exclosure. Protection excluded livestock defoliation and trampling but did not exclude possible wildlife activity.

Alfalfa plants were grazed using the mob grazing technique described by Bittman and McCartney (1994) to evaluate persistence of alfalfa populations. The technique should not be confused with the current practice of ultra-high stock density grazing described by Smart (2012). The term "mob grazing" can be subjective and with time it has been defined differently in both research and practice. Mob grazing in this study utilized longer grazing periods, lower stock densities, higher grazing frequencies, and shorter recovery periods than what is desired in ultra-high stock density grazing.

Mob grazing is efficient and convenient, and it may be more desirable than continuous grazing for identifying persistent alfalfa populations (Bittman and McCartney, 1994). Mob grazing allowed plants to regrow after grazing events, which facilitated data collection and provided additional productivity information. All alfalfa populations were uniformly grazed by beef cattle, either cow–calf pairs or yearling heifers, for 1 to 2 d. The livestock class used was dependent on animal availability. Alfalfa plants were grazed (to 2.6 cm stubble height) in order to achieve > 80% utilization. Grazing was initiated in August 2007. Frequency of grazing was one period in 2007, four periods in 2008, and three periods in 2009. Recovery periods between grazing periods ranged from 22 to 41 d. In 2008, the first grazing period occurred on 22 May and the last grazing period occurred on 20 August. Grazing in the spring of 2009 began on 29 May. Due to dry conditions in 2009, the last grazing period occurred on 4 August.

Data Collection

Initial alfalfa data were collected on 17 July 2007, before mob grazing was initiated. In 2008 and 2009, data were collected for grazed plants during spring green-up in May and regrowth in June and July. Data collection occurred shortly before each grazing event in 2008 but did not coincide with grazing events in 2009. Data for protected plants were also obtained on the same sampling dates. Plants were not grazed in 2010 to allow recovery. Final data were collected on 1 July 2010.

For both grazed and protected plants, presence or absence of alfalfa at each transplant location was determined. Absence of a plant indicated either plant mortality or dormancy. If a plant was present, average plant height (based on several stems) and canopy diameters were measured. Diameter measurements included the longest diameter (major axis) of the canopy **(A)** and the perpendicular (minor axis) dimension **(B)**. The diameters and height were used to determine canopy volume ($cm^3 \cdot plant^{-1}$) using the canopy volume formula of Thorne et al. (2002):

$$[2/3 \times \pi \times \text{Height} \times (\text{Diameter A}/2 \times \text{Diameter B}/2)] \quad (1)$$

Biomass ($g \cdot plant^{-1}$) of protected alfalfa plants was estimated by the same observer in July 2008, 2009, and 2010, approximating peak standing crop. Biomass of grazed plants was also estimated in 2010 when plants were allowed to recover from grazing.

Biomass was estimated using reference units, which is a modified nondestructive method used by Andrew et al. (1979) to estimate forage weight of shrubs. Reference units are hand-held shoots/branches that are usually 10% to 20% of the mean weight of the plants to be estimated (Andrew et al., 1979). Double sampling was used to calibrate observer biomass estimates. Fourteen alfalfa plants separate from the study were estimated using the reference units and then clipped. Clipped plants and reference units were oven-dried (60 °C) and weighed. A simple linear regression equation was developed using estimated plant biomass (number of reference units × reference unit weight) as the independent variable and clipped plant biomass as the dependent variable. Regression equations (Table 3) were used to correct weight estimates of study plants that were obtained using reference units. High coefficients of determination (R^2) indicate that most of the variation in clipped plant biomass was explained by the reference unit estimates. In practical terms, high R^2 values are an indicator of the observer's ability, within a year, to consistently (i.e., precisely) estimate biomass using reference units (P. S. Johnson, personal communication, April 2014).

A positive Spearman rank correlation ($r_s = 0.86$, $P < 0.01$, $n = 1\,168$) existed between canopy volume and reference unit estimated plant biomass. Uresk et al. (1977) developed a simple linear regression equation for big sagebrush to estimate total phytomass from shrub volume. Double sampling of biomass

Table 3
Regression equations used to correct reference unit estimates of individual alfalfa plant biomass at the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, South Dakota. Equations are based on reference unit estimated plant biomass (X) and clipped plant biomass (Y) of 14 alfalfa plants in each year.

Year	*n*	Regression equation[1]	R^2	*P* value
2008	14	Y = 0.968 (X)	0.94	<0.01
2009	14	Y = 6.644 + 0.894 (X)	0.94	<0.01
2010	14	Y = 25.146 + 0.826 (X)	0.90	<0.01

[1] Shapiro-Wilk test indicates ($P > 0.15$) that the error terms are normally distributed for each regression equation.

and canopy volume in this study resulted in a similar regression equation for alfalfa:

$$B' = 0.72558 + 0.11638 \times V' \tag{2}$$

where V is the double square root of canopy volume and B is the double square root of estimated biomass. The double square root transformation (M. H. Kutner, personal communication, March 2014) corrected heteroscedasticity and nonnormality of error terms. Biomass of protected plants in 2007 and grazed plants in 2007, 2008, and 2009 was estimated from canopy volume using the regression equation. Biomass estimates were transformed back to original units for statistical analysis.

Total alfalfa biomass (g) for each 7 m^2 replicate of a population was calculated using the following equation:

$$\text{Total biomass} = \sum_{i,\ j} b_{ij} \tag{3}$$

where b = biomass of the jth plant ($j = 1, \ldots, 7$) in each replicate on the ith sampling date ($i = 1$ in 2007; $i = 1, 2, 3$ in 2008 and 2009; $i = 1$ in 2010) within each year. Plants that were not present were assigned a biomass value of 0. Total alfalfa biomass was converted to forage yield ($kg \cdot ha^{-1}$).

Statistical Analysis

All data were analyzed using procedures in SAS (SAS Institute, 2008). Protected and grazed environments were analyzed as distinct groups, unless otherwise noted.

Several factors contributed to plant mortality following transplanting and during mob grazing. Removing environmental effects on mortality before mob grazing was initiated provides more information about effects of mob grazing exposure on survival. Survival of alfalfa in both protected and grazed environments was expressed as a percentage of established transplants on 17 July 2007. Mortality during the establishment period before mob grazing is excluded in this survival analysis.

Survival data were analyzed using PROC FREQ. A chi-square (χ^2) test was used to detect survival differences ($P < 0.05$) among the 11 populations and among environments (grazed and protected).

Estimated forage yield was analyzed among alfalfa populations in PROC MIXED. Population was treated as a fixed effect. Exclosure, replicate within exclosure, population-by-exclosure, population-by-replicate within exclosure, and residual were considered random effects. Consideration of exclosure as a random effect allowed inferences to be made to the regional landscape. LSMEANS calculated least squares means and standard errors. If fixed effects were significant ($P < 0.05$), the PDIFF option was used to separate means. Mean comparisons were considered different at $P < 0.05$.

Two sample t tests were conducted using PROC TTEST to detect differences between protected and grazed environments for mean individual plant biomass. Mean comparisons were considered different at $P < 0.05$.

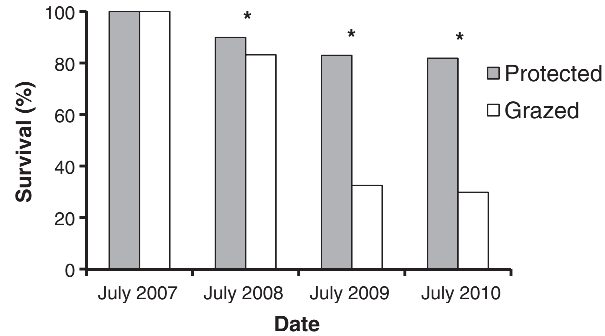

Fig. 1. Survival from July 2007 to July 2010 for protected and grazed alfalfa plants (pooled from three exclosures) at the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, South Dakota. Survival is a percentage of the no. of established plants on 17 July 2007. Survival percentages within a date with an asterisk are different at $P < 0.05$.

Table 4
Mortality during establishment from May 2006 to July 2007 for 11 alfalfa populations at the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, South Dakota.

Functional group	Population	Grazed plants[1]	Protected plants[2]
		--------------Mortality (%)[3]--------------	
Pure *falcata*	Don	43	21
Pure *falcata*	SD 201	19	26
Predominantly *falcata*	SD 203	21	17
Predominantly *falcata*	Falcata	23	19
Predominantly *falcata*	SD 202	21	17
Predominantly *falcata*	Mandan A9191	21	17
Hay-type *sativa*	Vernal	35	10
Hay-type *sativa*	Pioneer 5454	37	45
Hay-type *sativa*	Garst 6200HT	37	36
Pasture-type *sativa*	Travois	23	21
Pasture-type *sativa*	Alfagraze	30	19

[1] Mortality expressed as a percentage of 127 transplants for each population.
[2] Mortality expressed as a percentage of 42 transplants for each population.
[3] Establishment survival (%) = 100% − Mortality.

Results

Stand Persistence

Mortality During Establishment

Transplant presence observed on 17 July 2007 revealed that most alfalfa seedlings established successfully (Table 4). Many plants were flowering, and a few had been defoliated by wildlife. For replicates that would be mob grazed, mortality during the establishment period ranged from 19% for SD 201 to 43% for Don. Mortality for replicates that would be protected from mob grazing ranged from 10% for Vernal to 45% for Pioneer 5454.

Exposure to Grazing

Survival declined for both protected and grazed plants over the duration of the study, from July 2007 to July 2010 (Fig. 1). However, declines in survival with time were much greater for mob-grazed plants than protected plants. Despite dry conditions in 2009, alfalfa plant survival was stable from July 2009 to July 2010 for both grazed and protected plants.

Survival (Fig. 2) on 1 July 2010 was different ($P < 0.05$) among the 11 alfalfa populations subjected to mob grazing. Pure *falcata* and most predominantly *falcata* populations had higher survival than hay-type *sativa* and pasture-type *sativa* populations. Don had the highest survival (79%) under mob grazing while Alfagraze had the lowest survival (2%). For all populations except Don, higher mortality losses occurred during exposure to mob grazing than during the establishment period.

No difference ($P = 0.13$) in survival existed among populations that were protected from mob grazing. Survival ranged from 67% for 6200HT to 91% for SD 203.

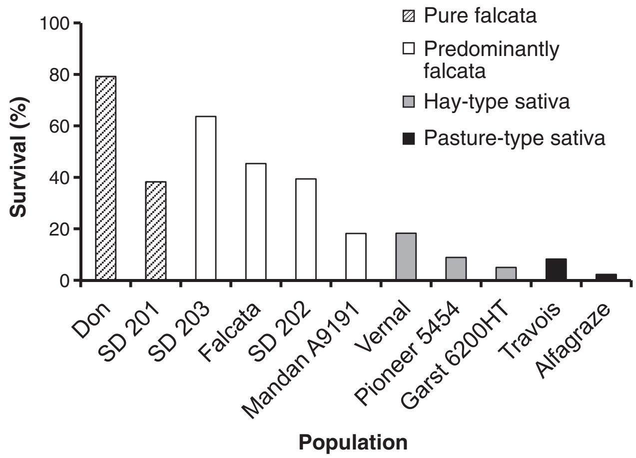

Fig. 2. Survival of 11 grazed alfalfa populations (pooled from three exclosures) on 1 July 2010 at the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, South Dakota. Survival is a percentage of the no. of established plants on 17 July 2007.

Estimated Forage Yield

Plant mortality that occurred during establishment did not result in estimated forage yield of initial stands differing ($P \geq 0.05$) among the 11 populations in July 2007 (Table 5). Initial stands of the 11 populations were therefore performing similarly before mob grazing was initiated in August 2007. However, differences ($P < 0.05$) in forage yield among the 11 populations became apparent in 2009, during mob grazing exposure. Forage yield of pure *falcata* and most predominantly *falcata* populations was higher ($P < 0.05$) than hay-type *sativa* and pasture-type *sativa* populations. In 2009, SD 203 had the highest ($P < 0.05$) yield under mob grazing. Don, Falcata, and SD 202 also performed well in 2009. Similar differences in yield among the 11 populations remained after mob grazing was discontinued and plants were allowed to recover in 2010.

Table 6
Mean individual plant biomass of protected and grazed alfalfa plants at the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, South Dakota.

	Initial stand	Mob grazing		Recovery
	July 2007[1,2]	May 2008[1,3]	May 2009[1,3]	July 2010[2,4]
	------------------------------ g·plant^{-1} (SE)--------------------------------			
Protected	11 (0.5) b[5]	3 (0.1)	15 (0.5) a	146 (6.4) a
Grazed	13 (0.4) a	3 (0.1)	8 (0.2) b	52 (1.1) b
P value	0.02	0.45	< 0.01	< 0.01

[1] Biomass estimated from canopy volume using regression equation.
[2] Peak standing crop biomass.
[3] Biomass present before the first mob grazing period of the growing season.
[4] Biomass estimated using double sampling reference unit method.
[5] Means within a column followed by different letters are statistically different ($P < 0.05$).

Estimated forage yield of protected plants is not presented for 2008 and 2009 because wildlife defoliated the alfalfa. Wildlife utilization of most protected plants did not exceed 25% in both years. Defoliation did not occur until after May but it precluded reliable estimates of growth and production in July. However, protected plants did not appear to be defoliated by wildlife in 2010 and differences ($P < 0.05$) in forage yield were evident in July (Table 5). Forage yield of predominantly *falcata* SD 203 (1 689 kg · ha^{-1}) was higher ($P < 0.05$) than mean yields for pure *falcata* and hay-type *sativa* populations.

Effect of Grazing on Individual Plant Biomass

In July 2007, mean biomass of individual plants that would be exposed to mob grazing was higher ($P < 0.05$) than plants that would be protected. However, this small initial difference had disappeared before the first mob grazing event of the 2008 growing season (Table 6). Mob grazing in 2008 resulted in plants having lower ($P < 0.05$) mean individual plant biomass than protected plants

Table 5
Estimated dry matter forage yield (kg · ha^{-1}) of 11 alfalfa populations at the South Dakota State University Antelope Range and Livestock Research Station near Buffalo, South Dakota.

		Grazed plants				Protected plants	
		Initial stand	Mob grazing		Recovery	Initial stand	Recovery
Functional group	Population	July 2007[1,2]	2008[1,3]	2009[1,3]	July 2010[2,4]	July 2007[1,2]	July 2010[2,4]
		--kg · ha^{-1}--					
Pure *falcata*	Don	46	82	57 b[5]	226 ab	77	750 cde
Pure *falcata*	SD 201	132	112	36 cd	141 cde	81	798 bcde
Predominantly *falcata*	SD 203	89	118	79 a	259 a	87	1 689 a
Predominantly *falcata*	Falcata	86	97	51 bc	198 abc	115	1 393 ab
Predominantly *falcata*	SD 202	134	109	57 b	162 bcd	93	1 117 abc
Predominantly *falcata*	Mandan A9191	116	98	25 de	78 ef	94	1 050 bcd
Hay-type *sativa*	Vernal	83	69	19 def	53 f	83	894 bcde
Hay-type *sativa*	Pioneer 5454	64	54	13 ef	22 f	55	318 e
Hay-type *sativa*	Garst 6200HT	73	70	4 f	12 f	67	487 de
Pasture-type *sativa*	Travois	87	75	13 ef	34 f	103	1 083 abcd
Pasture-type *sativa*	Alfagraze	58	58	5 f	5 f	77	619 cde
	SE	36	30	8	30	29	224
	P value	0.17	0.09	<0.01	<0.01	0.34	0.01

[1] Biomass estimated from canopy volume using regression equation.
[2] Peak standing crop biomass.
[3] Sum of forage biomass present before each mob grazing period in May, June, and July.
[4] Biomass estimated using double sampling reference unit method.
[5] Means within a column followed by different letters are statistically different ($P < 0.05$).

during initial spring growth in 2009 (Table 6). Differences persisted into 2010 despite discontinuation of mob grazing to allow plants to recover. In July 2010, mean individual plant biomass of protected plants was 2.8 times greater than grazed plants (Table 6).

Discussion

Differences in survival and forage yield among the 11 alfalfa populations exposed to mob grazing demonstrate that high persistence (long-term survival) is a necessary trait of alfalfa growing in semiarid environments. Pure *falcata* and most predominantly *falcata* populations with high survival (>38%) were better adapted to mob grazing in this environment than hay-type *sativa* and pasture-type *sativa* populations. Berdahl et al. (1989) also found that *falcata*-based alfalfas exhibited superior performance for persistence and one-cut forage yields when interseeded into semiarid rangeland.

Locally adapted, predominantly *falcata* populations SD 202, SD 203, and Falcata are suitable for dryland grazing in this region. SD 203 had higher survival and forage yield under grazing in 2009 than Falcata and SD 202. It appears that the higher percentage of *falcata* germplasm in SD 203 has likely contributed greater adaptability to this region. Peel et al. (2009) noted that pure *falcata* Don was intended for grazing in grass mixtures in the Intermountain West of the United States. However, this study also demonstrates Don is well adapted for dryland grazing in the Northern Great Plains.

Poor survival of the grazing-tolerant cultivar Alfagraze provides evidence that mob grazing contributed substantial stress. Frequency of mob grazing was similar to a high-frequency grazing system or hay cutting regimen (three or four cuts per growing season) for western South Dakota. Frequently harvesting immature alfalfa (vegetative to bud stages) can negatively affect stands and yield (Sheaffer et al., 1988). In addition, mob grazing modified the microenvironment in which alfalfa plants were growing by reducing ground cover and standing stubble height of associated vegetation.

Favorable growing conditions (i.e., moisture) in May and June 2008 (Table 1) likely encouraged regrowth and recovery following defoliation, thereby reducing detrimental effects of mob grazing. However, mob grazing was detrimental when growing conditions became dry and limited alfalfa regrowth after grazing in July 2008. Alfalfa will not necessarily recover (i.e., replenish reserves) after a grazing event if conditions for recovery are poor. Reserves may remain low if subsequent mob grazing precedes adequate recovery, which most likely occurred when plants were grazed in August 2008. When plant growth is limited (e.g., during dry periods), recovery periods may not provide any benefit (Briske et al., 2008).

Plant mortality from May through July in 2008 and 2009 was low for all mob-grazed populations. However, many grazed plants likely winterkilled during the winter of 2008–2009 (Fig. 1). Mortality losses were highest for hay-type *sativa* and pasture-type *sativa* populations. Alfalfa plants were covered by snowmelt, which froze into a layer of ice in November 2008 and then persisted under accumulating snow until March 2009. Anoxia may have contributed to alfalfa loss during the winter. However, protected plants had low mortality during the same winter (Fig. 1).

High dormancy in September 2008 may have contributed to increased winter survival of certain populations. Observations at that time revealed many plants were not present, particularly of the cultivar Don. Subsequent observation in May 2009 demonstrated that these missing plants had only been dormant. *Falcata*-based populations tended to have more dormant plants in September 2008 than populations in the hay-type *sativa* and pasture-type *sativa* functional groups. Winterhardiness is highly associated with fall dormancy (McKenzie et al., 1988), and winter survival will be improved by factors that limit fall growth, such as drought and high dormancy response (D. Undersander, personal communication, June 2009). Don will go dormant if moisture is not available (Peel et al., 2009), and the high survival of Don in this study may be attributed to high dormancy response when growing conditions are unfavorable.

Dormant plants probably maintained higher levels of reserves than plants that did attempt to regrow after the last grazing event in August 2008. Sufficient alfalfa regrowth after dormancy or defoliation is necessary to restore adequate levels of nonstructural carbohydrate reserves in the roots and crown (Sheaffer et al., 1988). Nondormant plants in September 2008 may not have produced sufficient regrowth before the first killing frost to restore adequate levels of reserves.

Initial spring growth of grazed plants following winter dormancy was slow compared with protected plants in May 2009 (Table 6). Slow green up is common when crown buds are not initiated in the autumn or if buds are damaged during winter (McKenzie et al., 1988). Autumn crown bud development (size and number of buds) is negatively affected by management that reduces reserves and stresses alfalfa (Sheaffer et al., 1988). Protected plants, however, likely had high levels of reserves and crown bud development was not negatively affected. Alfalfa that develops many crown buds in autumn is also able to recover faster from winter stresses (McKenzie et al., 1988).

Total precipitation in April 2009 through September 2009 was 69% of average, and temperatures were 1.8 ° C cooler than average (Table 1). Grazed plants did not make substantial regrowth after each mob grazing event. The 2010 growing season allowed grazed alfalfa plants to replenish reserves, flower, and set seed pods. Precipitation in April through June was above average (Table 1). However, the effect of management-induced stress on alfalfa plant growth and production was noticeable 1 year after mob grazing was discontinued. We observed that grazed plants tended to exhibit less erect growth and had fewer shoots than protected plants.

Grazing tolerance may not offer high persistence if the cultivar is not adapted to the regional environment. Alfagraze is not adapted to mob grazing in the Northern Great Plains. Previous research in North Dakota revealed poor persistence of Alfagraze under mob grazing (Hendrickson and Berdahl, 2003). Alfagraze was developed in Georgia where the winters are mild and the growing season is longer and more mesic. Poor survival of Travois, developed in South Dakota, may result from genotypic changes. Seed increase of Travois has reduced the contribution of *falcata* germplasm considerably (A. Boe, personal communication, 2009). Travois plants currently have purple flowers, coil-shaped pods, and an erect growth habit, indicating a high percentage of *sativa* germplasm. The original cultivar, released in 1962, had yellow or variegated flowers, sickle-shaped pods, and a decumbent growth habit (Rumbaugh et al., 1964). The cultivar was noted as being well adapted for grazing use in the Northern Great Plains.

Repeated mob grazing had detrimental effects on mean individual plant biomass and stand survival, which resulted in low forage yields. However, survival is the key factor affecting alfalfa yield under grazing. Differences in estimated forage yield among the 11 populations in July 2010 can be attributed to large differences in grazing survival. High individual plant productivity and stand persistence under no livestock grazing offers little benefit to a livestock producer if stand persistence under grazing is uncertain.

Implications

In this study, protected and mob grazed environments represent a gradient of low to high environmental stress levels. Management that limits alfalfa stress will maintain stands and productivity potential of individual plants in the stand, resulting in high forage yields. However, accumulating stress caused by repeated grazing that weakens plants can result in high environment-related mortality (e.g., winterkilling) and poor forage yields. Alfalfa in most semiarid grazing environments will likely be exposed to stress levels that fall within the extremes of this study. However, alfalfa populations such as SD 203 and Don that can survive extreme stress and recover are necessary for grazing use in semiarid environments. Alfalfa will occasionally be exposed to harsh conditions, such as heavy grazing pressure, even under good grazing management (Ries, 1982).

Using hay-type and/or nonadapted populations for dryland grazing in semiarid regions is discouraged because persistence can be poor. Most of the *falcata*-based populations evaluated in this study are well adapted to the Northern Great Plains and have high potential for dryland grazing. Incorporating *falcata*-based alfalfas into production systems will provide many benefits to producers. Interseeding alfalfa into native rangelands and tame pastures has been successful (Lorenz, 1982; Smith, 1997). However, introducing alfalfa into native rangelands may not be suitable for some land managers (Xu et al., 2004) and decisions to plant alfalfa will depend on management priorities.

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