Mob vs. Rotational Grazing: Impact on Forage Use and *Artemisia absinthium*

Heidi Reed, Alexander Smart, David E. Clay,
Michelle Ohrtman and Sharon A. Clay

Additional information is available at the end of the chapter

Abstract

Short duration (≤24 h), high stocking density grazing systems (e.g., mob grazing) mimics historic prairie grazing patterns of American bison (*Bison bison*), and should minimize selective grazing. We compared mob [125 cow-calf pairs on either 0.65 ha for 12 h; or 1.3 ha for 24 h] vs. rotational [25 cow-calf pairs on 8.1 ha for 20 days starting in mid-May with or without 2,4-D application prior to grazing; and 15 days starting mid-April (no herbicide)] grazing systems based on forage utilization and impact to *Artemisia absinthium* (absinth wormwood) in a tall grass pasture of Eastern South Dakota. Grass height and density, and *Artemisia absinthium* patch volume were quantified pre- and post-grazing at sampling points along multiple transects. Mob grazing had >75% forage utilization, whereas rotational grazing averaged 50% (all consumption). Within a grazing season, three grazing systems suppressed *Artemisia absinthium* patches with rotation/spray (100% decrease) > mob (65 ± 10% decrease) > mid-May rotation (41 ± 16% decrease), whereas *Artemisia absinthium* patches in the mid-April rotation followed by summer rest dramatically increased in size. *Artemisia absinthium* patches <19,000 cm^3 were browsed, whereas larger patches were trampled in mob-grazed areas, but avoided in rotational grazing. All *Artemisia absinthium* patches had regrowth the year following any grazing event.

Keywords: cattle, forage utilization, mob grazing, rotational grazing, weed management

1. Introduction

Grazing lands are managed to optimize forage and animal productivity, and minimize adverse impacts to soil and the surrounding environment. The annual economic impact of

all weedy species in U.S. grazing lands is greater than all other pests combined [1], and has been estimated at 1 billion dollars for forage loss and 5 billion dollars for control costs [2]. Weed infestations cause a variety of problems in grazing lands. Weeds can reduce forage vegetative quality and quantity; displace native plants and animals; reduce animal fertility, weight gains, or be toxic, resulting in fatalities; reduce meat and/or hide quality; increase management costs; and reduce land values [3, 4]. Tactics for weed management in pastures and grazing lands vary with the type of weed, livestock species, and applicability of other methods (e.g., mowing, biocontrol, herbicide treatment) [5, 6].

Livestock can help manage weeds by grazing or trampling and can improve pasture condition and competitiveness of desirable plants by increasing soil nutrients through manure and urine deposition [3]. Weed species and stage of growth; livestock species; and stocking rate and duration influence grazing effectiveness on weeds [3, 7]. Unfortunately, cattle (*Bos taurus*), the grazing livestock of choice in the Northern Great Plains (NGP), selectively consume forage in dung-free areas [8, 9], and avoid weeds for a wide variety of reasons [10]. Cattle herds are not managed specifically for weed control for several reasons. First, cattle are expensive to raise and replace and, even with premium prices, the economic margin is narrow [7]. Weeds may not be as palatable as grasses, and lower consumption may reduce weight gains [7], or, if high in alkaloids, problems with reproduction and/or toxicity can occur [11].

Rotational grazing often uses a 'take half'- 'leave half' forage philosophy to maintain healthy, vigorous plant communities [12, 13]. Mob grazing has been promoted to mimic the world's historic grassland ecosystems [14] with herds of large animals intensively grazing areas and moving often. The definition of mob grazing is subjective, but typically includes using extremely high stocking rates (100 head or more per ha) for short periods of time (moving every 12 or 24 h) [15] followed by recovery periods of 6–12 months. The goal of mob grazing is to have every plant within the enclosure eaten [16] or trampled [17], limiting selectivity or avoidance of specific species [9], and providing a more homogeneous grazing treatment. Barnes et al. [16] reported that grazing homogeneity correlated with paddock size, with pastures ranging from 1 to 8 ha in size grazed nearly uniformly, even if the same stocking rate per ha are used on larger areas.

Grazing impact for weed management is maximized when the target weed is most palatable, is the only forage option, or is made more palatable to livestock in some way (e.g., salt or sugar treatment) [7], and the desired vegetation is at its least vulnerable phenotypic stage [1]. High animal densities maximize trampling, which incorporates plant litter, manure, and urine into soil, increasing organic carbon and soil nutrients [17]. The combination of eating, trampling, and long rest periods is expected to increase productivity of more desirable forage [3, 18].

Mob grazing has been adopted by ranchers in Texas, SE Colorado, central Nebraska, Missouri, and other areas [19] where vegetative regrowth can occur quickly due to warm conditions, and high rainfall or irrigation capabilities. Under dryland conditions of the NGP, timing mob grazing to fit within the vegetative and environmental constraints of the area is difficult as growing seasons are short, and pastures often experience summer drought. McCartney and Bittman [20] reported on a mob grazing study that used 7–14 heifers ha^{-1} (dependent on seasonal timing) on about 0.3 ha paddocks at different intensities (light, grazed twice a year; to intense, grazed five times a year) in northeastern Saskatchewan. They observed positive

[decline in smooth brome (*Bromus inermis*)], negative [decline of intermediate wheatgrass (*Elytrigia repens*), and increase bluegrass (*Poa* sp.) species], or no effects on specific species [e.g., green needlegrass (*Nassella viridula*)] over 4 years. These findings suggest that intensive grazing benefits are related to plant species, stocking density, and grazing timing, all of which can be manipulated for maximum impact [21]. Ranchers interested in using mob grazing for increased productivity and harvest efficiency would benefit from on-farm research that examines the relationship among stocking densities and timing on vegetative utilization and the impact to locally invasive weed species.

There have been few comparisons in the NGP among mob grazing and other, more conventional, grazing systems. Fundamental problems in grazing research often include small enclosure sizes and animal numbers, which provide data that are difficult to scale to commercial operations [16]. Due to the expense, need for many animals, and labor and time involved to move cattle frequently, the study was managed by an Eastern South Dakota rancher who incorporates both rotational and mob grazing techniques into his cattle operation. *Artemisia absinthium* was selected as a model invasive plant as it is a non-native perennial forb that cattle typically avoid due to woody stems of older plants, and unpalatability due to the production of secondary compounds and essential oils [22]. The objectives of this study were to (1) quantify forage present before grazing (pre-graze) to be able to estimate forage utilization post-graze in mob and rotational grazing systems, (2) determine the impact of grazing system on *Artemisia absinthium* suppression in-season based on mob and rotational grazing and (3) examine the recovery of *Artemisia absinthium* patches a year after mob grazing.

2. Grazing impacts to forage utilization and Artemisia absinthium

2.1. Experimental site

The effects of rotational and mob grazing stocking densities on Artemisia absinthium and surrounding forage utilization were compared in an eastern South Dakota rangeland location in the tall grass prairie habitat near Hayti (44.66°N, −99.22°W) in 2013 and 2014 [23]. The dominant soil series of the rotationally grazed pasture were the: Poinsett-Waubay silty clay loams (Calcic Hapludolls/Pachic Hapludolls); Buse-Poinsett complex (Typic Calciudolls/Calcic Hapludolls); and Poinsett-Buse-Waubay complex (Calcic Hapludolls/Typic Calciudolls/Pachic Hapludolls) [https://soilseries.sc.egov.usda.gov/osdname.aspx]. Mob grazing pasture soils were similar to the rotational pasture with the addition Barnes-Buse loam complex (Calcic Hapludolls/Typic Calciudolls). The plant communities in these pastures were a mix of cool season native and invasive grasses, warm season grasses, and broadleaf species (**Table 1**).

2.2. Weather

Growing degree days (GDD) were calculated to provide a reference for plant development between sampling dates and years. The GDD calculation [GDD = $\sum$ (maximum daily temperature + minimum daily temperature)/2 − base temperature] used the base temperature of 0°C, due to majority of cool season species with GDD accumulations starting on January 1 of each year.

Mob-grazed sites		Rotational sites	
Common name	Scientific name	Common name	Scientific name
Big bluestem	*Andropogon gerardii*	Western wheatgrass	*Pascopyrum smithii*
Sweet clover	*Melilotus officinalis*	Absinth wormwood	*Artemisia absinthium*
Alfalfa	*Medicago sativa*	Smooth brome	*Bromus inermis*
Red clover	*Trifolium pratense*	Kentucky bluegrass	*Poa pratensis*
Kentucky bluegrass	*Poa pratensis*		
Dandelion	*Taraxacum officinale*		
Absinth wormwood	*Artemisia absinthium*		
Western wheatgrass	*Pascopyrum smithii*		
Smooth brome	*Bromus inermis*		

Table 1. Plant species in the mob-grazed and rotational grazed sites at Hayti, SD in 2013 and 2014.

Precipitation (from January 1) was also determined. The rotational pre-graze samples in 2013 were taken on June 13, with 641 GDD and 243 mm precipitation (www.noaa.gov) with values similar to the 30-year (1980–2010) average. Post-grazing samples were taken July 22, with GDD of 1540 and precipitation totaled 343 mm. In 2014, samples were taken May 13 with GDD at the spring assessment (which was taken after the early spring grazing) 262 and 65.5 mm of precipitation. The fall assessment was taken September 16 with GDD of 2603, and total rainfall of 370 mm fall. Rotational grazing was done much earlier in 2014 because the rancher was concerned about low amounts of precipitation (nearly 60% below average) during the 2013 fall and winter.

GDD accumulations for mob-grazed areas in 2013 were 1801 (August 6) and 1855 (August 9) for pre- and post-graze samples, respectively. Precipitation totaled 376 mm before and after mob grazing. In 2014, GDDs were 1693 pre-graze (July 29) and 1817 post-graze (August 4) and precipitation for pre-graze and post-graze totaled 230 and 270 mm, respectively.

2.3. Grazing treatments

Stocking treatments (rotation vs. mob) were repeated, although cattle densities and time of grazing differed between the 2 years due to feeding needs and differences in forage growth due to low rainfall in 2014 (**Table 2**). Rotational grazing was conducted in 8 ha pastures with 25 cow-calf pairs (1560 kg ha^{-1}). In 2013, in one paddock, the cow-calf pairs were allowed to graze for 14 days starting June 13 (referred to as 'rotation'). In a separate paddock, generic 2,4-D ester at 1.1 kg ha^{-1} [24] was applied 1 day before the start of grazing on June 13 with a grazing duration of 14 days (referred to as 'spray/rotation'). In 2014, a different pasture was grazed by 25 cow/calf pairs for 15 days, starting April 27 and ending May 11 (referred to as 'early spring grazed/summer rest').

Mob grazing was conducted for 12 h in a 0.65-ha paddock on August 8, using 125 cow-calf pairs (stocking rate of 223,250 kg ha^{-1} day^{-1}) (**Figure 1**). In 2014, a different 1.3-ha area was mob grazed on July 30 for 24 h with 125 cow-calf pairs (stocking rate of 53,580 kg ha^{-1} day^{-1}).

Year	Grazing system	Stocking density	Grazing duration	Pre-graze		Post-graze	Biomass[1]			
				Sampling date	Forage biomass[1]	Sampling date	Standing	Trampled[2]	Forage use efficiency[3]	Forage utilization[4]
		kg ha⁻¹			kg ha⁻¹		kg ha⁻¹		%	%
2013	Mob	223,250	12 h	6-Aug	2910[a5]	9-Aug	570[b]	530[b]	62	80
	Rotation	1560	20 days	13-Jun	2600[a]	22-Jul	1190[b]	0	45	45
	Rotation/spray	1560	20 days	13-Jun	4530[a]	22-Jul	2528[b]	0	57	57
2014	Mob	53,580	24 h	29-Jul	4640[a]	4-Aug	1170[b]	1890[b]	34	75
	Rotation/ Summer ungrazed	1560	15 days		~1700[6] (estimated)	13-May 16-Sep	870 2090[7]			

[1]Vegetation biomass was estimated using the cool season mixed pasture grazing stick method, (vegetation height cm − 7.6 cm) * 79 to estimate kilograms per ha.

[2]Trampled vegetation was any plant with a stem less than a 450 angle from the soil surface.

[3]Forage efficiency (consumption only) was calculated by: [(before grazing vegetation −[standing + trampled])/(before grazing vegetation)]*100.

[4]Forage utilization (consumption + trampling) was calculated by: [(before grazing vegetation − standing vegetation after grazing)/before grazing veg]*100.

[5]Values with different letters within the same row for the pre graze vegetative biomass compared with post-graze standing or trampled (mob) or total vegetative biomass (rotational) differed at P < 0.0001.

[6]Samples were not taken pre-graze in this treatment but estimated from the leave half/take half grazing system.

[7]Forage in autumn following the grazing treatment in the spring.

Table 2. Mob and rotational grazing stocking density, grazing duration, sampling dates, forage biomass pre- and post-graze, and forage efficiency and utilization by year.

Figure 1. A mob grazing herd waiting for the next pasture.

2.4. Forage amounts and utilization

Eight 50-m long transects were established in each paddock for vegetative production evaluation. Sampling points were placed every 5 m along each transect, with GPS coordinates (Garmin etrex 20, Garmin, LTD, Schaffhausen, Switzerland) recorded so that resampling occurred at the same points pregrazing and post-grazing. At the sampling points, pre-graze measurements (in 2013, rotational graze and spray/rotational graze—13 June; mob graze—6 August; 2014, mob graze—29 July) included vegetation height using a grazing stick [25], and ocular estimates of basal cover of living vegetation, litter cover, and bare ground (0–100%) in a 1 m^2 area around the point. In 2013, vegetation in a 0.25 m^2 area was clipped to within 1 cm of the soil surface, and bagged (n = 30). Litter under the vegetation also was collected. Samples were weighed, dried at 38 C to constant weight, and dry weight of vegetative biomass and litter per unit area were calculated. The biomass values and grazing stick estimates were compared at each sampled point.

A few days after grazing (in 2013, rotational graze and spray rotational/graze—22 July; mob graze—9 August; in 2014, mob graze—4 August), the same transects and sampling points were reestablished for post-grazing measurements. Vegetation height was measured using the grazing stick, and percent trampled vegetation (e.g., new litter; defined as living vegetation oriented less than 45° from the soil surface) was estimated in the same areas as pre-graze sampling.

In 2014 due to the producer's needs, cattle grazed the designated rotational pasture in April and then this pasture was untouched for the remainder of the season (summer rest). Unfortunately, due to the early timing of the grazing in the second year, no pre-grazing measurements were taken for this pasture. Measurements occurred on 13 May, after the early season grazing was completed, and then resampled on 16 September (designated as regrowth after early spring grazed/summer rest). In addition, the transects which were sampled in 2013 were reestablished and vegetative height was quantified in May 2014 to examine recovery after grazing.

2.5. *Artemisia absinthium* measurements

Another three 50-m transects were established in each pasture with vegetative height measured pre- and post-graze every 2.5 m along the transects. *Artemisia absinthium* patches (individual plants if small or a patch if large) were selected and tagged near the base of the plant/patch every 5 m along these transect lines in each treatment (in 2013 rotation; spray/rotation; and mob graze; and 2014 rotation/summer rest and mob graze). Pre- and post-grazing grass height and *Artemisia absinthium* patch volume (height and two perpendicular widths) were measured at the same time as forage measurements in 2013. In late May of 2014, *Artemisia absinthium* patches measured in 2013 experimental pastures were inspected for recovery and shoot regrowth. The rotation/summer rest had *Artemisia absinthium* measurements taken in May, 2014 just after grazing, and again in September (as summer rest measurement).

2.6. Statistical analysis

Data analyses were performed using JMP®, Version 5.0.1, (SAS Institute Inc.). Forage amounts pre-graze were based on clipped biomass measurements and compared with the grazing stick method. The grazing stick equation, based on plant height, was:

$$\text{Estimated biomass} \left(\text{kg ha}^{-1}\right) = \left[\text{plant height (cm)} - 7.6 \text{ cm}\right] \times 79 \tag{1}$$

This estimated biomass for a cool season mixed grass pasture [26, 27]. The 7.6 cm value accounts for basal stems and leaves that would not be eaten by grazing animals. Two-tail, two-sample homoscedastic t-tests were used to compare forage biomass with the grazing stick estimates. Grazing stick estimates were found to be statistically similar to the clipping method.

Forage biomass and *Artemisia absinthium* volume were compared pre- and post-grazing and forage utilization (consumption plus trampling) was determined by examining new litter and remaining biomass at each transect point. These data were analyzed using one-tailed (post-graze < pre-graze) matched pair t-tests. Due to timing and treatment differences among rotational treatments, data were analyzed by treatment and year. Treatment differences are reported at a significance level of $P \leq 0.10$.

Binomial analysis of *Artemisia absinthium* patch volume data (yes = less volume post grazing; no = same or greater volume) using the equation:

$$\left[p \pm t_{(0.1)} \text{ sqrt} \left(p \left(1 - p\right)/n\right)\right] \tag{2}$$

was used to examine the influence of each treatment on *Artemisia absinthium* patches [28]. In the mob grazing treatments, *Artemisia absinthium* data were combined across years. To better understand the relationship between weed patch size and grazing system impact, *Artemisia absinthium* patches were separated into two volume classes (<19,000 cm^3 and >19,000 cm^3). In Myer [23], four volume classes originally were designated, but were combined into the two volumes due to similarity of results within smaller and larger size classes.

3. Measured impacts of grazing systems

3.1. Forage utilization

3.1.1. Mob grazing

Pre-graze forage coverage averaged 85% (grass and forb) in 2013 and neared 100% in 2014. In 2013, pre-graze forage biomass was estimated to be 2910 (±816) kg ha^{-1} with the clipped method and 2720 kg ha^{-1} with the grazing stick. These measurements were statistically similar. Pre-grazing biomass in 2014 averaged 4640 kg ha^{-1}, the grazing stick method estimated 3980 kg ha^{-1}, with estimates statistically similar. The discrepancy between direct biomass sampling and grazing stick can be partially explained by sampling method, as forage was cut to within 1 cm of soil level, but the grazing stick calculation subtracts 7.6 cm from forage height to account for unconsumed stubble. Whereas the clipping method provided excellent data, the process was labor intensive, slow, and required preweighing, drying, and postweighing. In addition, it was found that after mob grazing there was no biomass to clip. The grazing stick method provided a reasonable estimate of available forage.

In 2013, mob grazing forage utilization was about 80% (**Table 2**; **Figure 2**) with a harvest efficiency (amount consumed) of 62% (~1800 kg ha^{-1}). The remaining 20% of the vegetation was trampled. In 2014, the same stocking rate (125 cow-calf pairs) was used, but the area was two times larger, had about 1.5 times greater pre-graze biomass, and grazing time was doubled from 12 to 24 h. Forage utilization in 2014 was 75%, similar to 2013. The amount consumed was 1600 kg ha^{-1}, similar to the amount consumed in 2013, but due to the greater starting biomass, the harvest efficiency (percent consumed) was 34%, and the trampled amount was 40%.

3.1.2. Rotational grazing

In 2013, pre-graze forage amount averaged 2600 kg ha^{-1} and post-graze was 1190 kg ha^{-1} (**Table 2**). Both harvest efficiency (amount consumed) and utilization (amount consumed + trampled) were 45%, as new trampled litter was not observed. In the rotational/spray treatment,
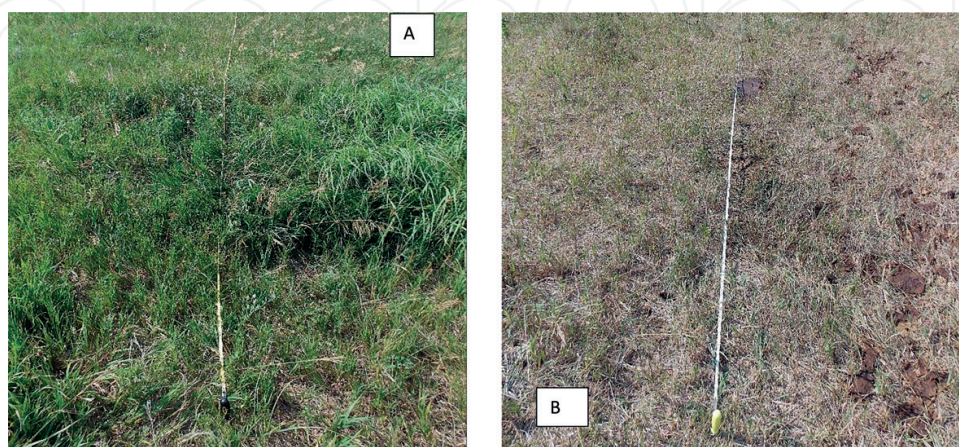

Figure 2. Pre-graze forage and post-graze results, the impact of mob grazing.

pre- and post-graze forage was 4530 and 2610 kg ha^{-1}, respectively, which indicated that forage consumption neared 57%. As in the rotational area, there was little newly trampled litter.

The 2014 rotational pasture was grazed in April, which allowed recovery during the summer/fall of 2014. Forage after grazing was 870 kg ha^{-1}. The rancher follows the 'take half, leave half' utilization recommendation [12, 13], so a reasonable pre-graze forage estimate would have been about 1300 kg ha^{-1}. Grass forage increased from 11 (May) to 23 (September) cm in height ($P < 0.001$) with fall forage biomass estimated at 2090 kg ha^{-1}.

3.2. Grazing impact on *Artemisia absinthium*

A pre-grazing assessment of *Artemisia absinthium* was conducted with the volume of the patch related to its dry biomass by recording patch volume and comparing with clipped dried biomass. In mid-June of 2013, 30 *Artemisia absinthium* patches were quantified for volume, plants clipped, and dry biomass determined before grazing. Regression analysis of biomass (expressed as log biomass +1) on plant volume (expressed as log plant volume + 1) for these 30 patches resulted in the equation: log (biomass+1) = 1.35 log (volume + 1) − 5.89, [23] which implies a direct increase in biomass as patch volume increased. This regression fit the data very well (r^2 = 0.90; $P < 0.001$), and was intended to be used to express differences in *Artemisia absinthium* biomass pre- and post-grazing. However, trampling dramatically increased *Artemisia absinthium* plant volume, as the shoots spread apart, in the mob-grazed areas (**Figure 3**) but because the samplings were within a few days of each other, it would not have been possible to increase biomass as the equation suggests. Therefore, data are presented and discussed in terms of plant volume, rather than biomass.

3.2.1. Mob grazing

Matched-pair analysis of 2013 and 2014 combined indicated that about 65% of the *Artemisia absinthium* patches had less volume after mob grazing (**Table 3**). In 2013 the decrease averaged 75%, whereas in 2014, the decrease was about 20%. In 2014, grass surrounding the *Artemisia absinthium* patches had 60% of the forage consumed. Therefore, it appeared that cattle were grazing close to,
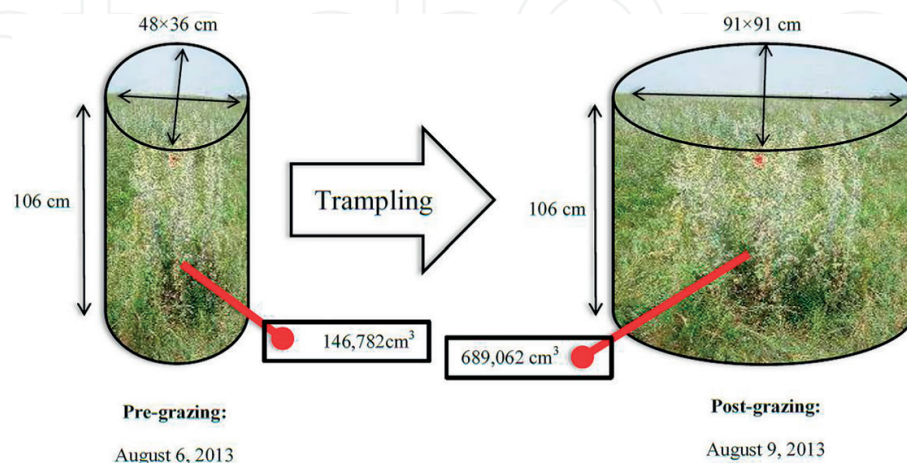

Figure 3. Example of the impact of mob grazing on a single *Artemisia absinthium* plant (pre and post grazing).

Year	Grazing system	Post-graze			
		Pre graze ave. vol.	#Decrease/total	Ave. vol. of remaining	% Control[a]
		cm^3		cm^3	
2013/2014	Mob	66,500	39/60	25,650	65 (10)
		<19,000	28/38		73 (9)
		>19,000	11/22		50 (NS)
2013	Rotation	12,380	12/29	8830	41 (16)
	Spray/rotation	16,500	26/27	0	100 (1)
2014	Summer recovery	2850	1/28		3 (NS)

The average pre-graze volume, the number of patches from the initial number that decreased in volume post-graze, and the average volume of the patch remaining. Patches in the mob-grazed pastures were separated into those with an initial volume < or >19,000 cm^3 and number that decreased in volume are presented.[a]Numbers in parentheses are confidence intervals based on binomial testing of the number of patches that showed a decrease over the total number with t = 0.1.

Table 3. Effect of grazing system on *Atremesia absinthium* average patch volume.

if not directly on, the *Artemisia absinthium* plants. The remaining patches increased in volume by 120% in 2013 and 154% in 2014. This volume increase at first does not seem correct, as pre- and post-grazing samples were taken within days of each other each year. However, the volume increase was due to an increase in patch width (**Figure 3**), and was attributed to trampling.

3.2.2. Rotational grazing

In 2013, 41% of the *Artemisia absinthium* patches in the rotational paddocks had a 30% decrease in volume and the remaining patches had similar volume pre- and post-grazing. Post-graze forage height of plant near the *Artemisia absinthium* patch averaged 15 cm (33%) shorter than pregrazing measurements ($P < 0.001$), which indicates that *Artemisia absinthium* may have been consumed. In the spray/rotation 2013 pasture, nearly 100% of the *Artemisia absinthium* patches decreased in volume by 100% after grazing (**Table 3**). Grass surrounding the *Artemisia absinthium* patches was 51% shorter ($P < 0.001$) post- grazing, which strongly suggests that plants in the sprayed patches were consumed with forage.

In 2014, with no grazing pressure during the summer season, only 1 (3%) of the *Artemisia absinthium* patches decreased in volume. The remainder had a volume increase of 5000% from May (average volume = 2850 cm^3) to September (average volume = 151,200 cm^3). In addition, the average height increased from 15 (May) to 86 cm (September). Because there was no trampling and an increase in shoot height, this increase can be attributed to plant growth.

3.2.3. Influence of initial Artemisia absinthium patch volume on grazing system impact

Initial *Artemisia absinthium* patch volume in the rotation and rotation/spray areas did not influence final volume. All *Artemisia absinthium* size categories in the rotationally grazed areas had about 50% of the patches increase and 50% decrease in volume. All *Artemisia absinthium* patches in the rotation/spray treatment were reduced to near 0, irrespective of initial plant volume. Initial *Artemisia absinthium* patch volume in mob-grazed areas influenced final *Artemisia absinthium* volume.

When data were combined over both years, 28 of 38 *Artemisia absinthium* patches <19,000 cm^3 decreased in volume with reductions ranging from 43 to 84% (data not shown). The other 10 patches in this category increased in volume by about 50%. There were 22 *Artemisia absinthium* patches >19,000 cm^3. Of these, 11 patches had a slight decrease in volume. The volume increase in the other 11 patches averaged 150%. Based on the height of the surrounding forage and *Artemisia absinthium* plant condition, it appears that *Artemisia absinthium* patches <19,000 cm^3 were consumed with forage, whereas plants in the larger patches were trampled and not browsed.

Artemisia absinthium plant height also was used to evaluate treatment effects. The average height of 30 *Artemisia absinthium* plants was similar before (average height 39 cm) and after (average height 37 cm) rotational grazing in 2013, which may be considered avoidance. The initial height [tall (>33 cm) vs. short (<33 cm)] did not influence rotational grazing impact. Before grazing, *Artemisia absinthium* plant height in the mob-grazed treatment averaged 58 cm. After mob grazing, 75% (± 9) of the *Artemisia absinthium* plants were 37% shorter, with no plants increasing in height. Even plants that were very tall (>97 cm) were reduced in height by about 50%. These data were consistent with either trampling or consuming. We concluded that animals in the rotation pasture had enough area and forage to selectively avoid *Artemisia absinthium* plants. Spraying 2, 4-D followed by rotational grazing (spray/rotation treatment), however, resulted in a height reduction of 96% of the *Artemisia absinthium* plants (from 54 to 9 cm).

In 2014, all tagged patches in the 2013 pastures were reevaluated to determine if patches and plants in the patches were still present and the amount of regrowth. Plants in the treated patches of the rotation/spray treatment, which provided excellent control of *Artemisia absinthium* in 2013, had less volume than those originally measured in 2013, but *Artemisia absinthium* plants were still present at the same location as the original patches (data not shown). Rotational grazing, with a 2,4-D application just prior to grazing, helped manage *Artemisia absinthium* plants in the same growing season as the herbicide application as they were no longer visible just after grazing. However, this treatment did not eliminate this perennial weed, as plants regrew the year after this treatment. Plants in the mob-grazed and rotational grazed areas were also present and had no observed injury.

4. Discussion

Rotational grazing for 20 days at 25 cow/calf pairs in 8 ha had comparable results in forage consumption to mob grazing with 125 cow/calf pairs for 12 or 24 h. in 0.65 or 1.3 ha, respectively. There were other differences between the systems, most notably the vegetative growth stage of forage, which was more mature during mob grazing. Trampled vegetation was observed in the mob grazing areas but not the rotational grazing treatments. However, claims about building soil at rates of cm per year, or significantly increasing N and C content (which was measured and reported in Myer [23]), as often discussed in popular press articles [15, 19], could not be substantiated in this study. However, trampled litter and manure patches (measured as manure patches along the transects and reported in Myer [23]) were greater post-mob grazing compared to both pre-mob and post-rotational grazing.

McCartney and Bittman [20] and others [29–31], suggest that timing and grazing capacity for optimal forage utilization and weed control, with minimal harm to desired species, requires thoughtful management to improve or maintain rangeland health. Our results show that mob grazing (225,000 or 50,000 kg of cattle ha^{-1} day^{-1}) could reduce biomass of *Artemisia absinthium* a less palatable species in a pasture. In mob-grazed treatments, *Artemisia absinthium* plants appeared to be consumed if plants were small and, most likely, still had herbaceous, rather than woody, stems. Mob grazing offers the additional benefit of trampling which reduced *Artemisia absinthium* height, although not necessarily the volume, especially of larger plants. Effectiveness of mob grazing is dependent on plants species present, stocking density, and timing [14, 16, 20]. Grazing weeds should be avoided after seed set to minimize seed dispersal, as some weed seeds remain viable or increase in germination after ingestion and passing through the digestive tract of livestock [32, 33]. While we did not find literature that specifically addresses changes in *Artemisia absinthium* seed viability after animal ingestion, *Artemisia absinthium* seeds mature in late August or September [34], after the grazing events of our study, and was not investigated. If grazing an infested pasture must be delayed until a species is past its most palatable stage, or if a weed has inherently low palatability, higher stocking rates, as seen in this study and other studies [7] improved suppression.

Mob grazing with cattle has been proposed as a grazing system to increase forage use efficiency and help in landscape restoration [14] and is likened to grazing patterns of the native plains bison. Kohl et al. [35] reported that bison and cattle differ in grazing, standing, bedding, and moving behaviors, with bison moving from 50 to 99% faster and foraging up to double the land area than cattle during the same duration. This is the precedent for the frequent moves when mob grazing cattle. In addition, cattle, when not pressured, tend to select high plant biomass, whereas bison tend to select intermediate plant biomass [35]. Regardless of the inherent differences between these two species, when managed correctly, mob grazing with cattle can diversify grazing time, with frequent moves, and long rest periods [30]. However, if managed incorrectly, high intensity grazing systems could increase weed infestations [31]. For example, in 3 years, under medium grazing intensity (grazed five times year^{-1} with 6 cm of vegetation remaining after each grazing event) weeds increased by about 4 plants m^{-2}, whereas under high intensity (grazed seven times year^{-1} until surface exposure), weed densities increased by 51 plants m^{-2} [36]. Hart et al. [37] reported that stocking rates that alter grazing frequency and defoliation intensity, rather than grazing system, have greater potential to impact species composition. Plant diversity and complex mixtures of forage species are integral to healthy ecosystems and consistent yields [38, 39]. However, mob grazing, if repeatedly used in the same area and at the same seasonal timing, could decrease plant species diversity and richness, change functional plant traits (e.g., tall vs. short), but improve productivity of the remaining plants [40].

The animal of choice for grazing also can influence grazing results. Goats (*Capra aegagrus hircus*) and sheep (*Ovis aries*) [7, 41] are often suggested to control brush and other undesirable vegetation, as they are more efficient at foraging and have faster growth rate than cattle. However, there are to numerous disadvantages to using goats and sheep which include: poor return on investment due to low per capita consumption of their meat products in the US and low wool prices; limited genetic improvement in milk or meat production; high predation rates compared with cattle; difficulty in fencing confinement; and susceptibility to internal

parasites, which discourages multiple species grazing [41–43]. Cattle are, by far, the grazing animals of choice in South Dakota (1.8 million cattle vs. 260,000 sheep) [44] and across the Northern Great Plains of the US.

Herbicide applications are reported to be the most effective methods for *Artemisia absinthium* control [22, 45–47]. There are numerous reports about the enhanced effectiveness of combining weed control strategies for weed suppression in grazing lands [1, 7, 47–49]. In this study, using 2,4-D ester herbicide in combination with grazing, helped remove *Artemisia absinthium* growth for the first growing season. Some herbicides affect the palatability of certain plants, encouraging livestock to eat plants they would normally avoid, like poisonous plants [50]. However, precautions must be taken if spraying 2,4-D [24] because this herbicide can cause plants to accumulate excess nitrate, become more palatable, and result in nitrate poisoning of livestock [51]. There are a few grazing restrictions for 2,4-D ester [24]. For example, meat animals could be grazed immediately after application, but not within 7 days of slaughter; and restrictions for a dairy animals differed with no grazing within 7 days post-application.

5. Conclusions

Healthy rangelands grow more grass which aids in *Artemisia absinthium* control by preventing infestations and providing competition to newly establishing plants. Grass density can be optimized by managing livestock to minimize overgrazing through rotational grazing or avoiding heavy, early season grazing [22]. Based on *Artemisia absinthium* size increase in the 2014 recovery area after the early spring rotational grazing/summer rest, it appears that rotational grazing later in the growing season (as in 2013) achieved better suppression of *Artemisia absinthium* patches, although cattle did not necessarily consume *Artemisia absinthium*.

Once present, our study showed that grazing provided temporary reductions to *Artemisia absinthium* patches, with greater reductions in the mob-grazed and rotational/spray treatments than the rotational grazed treatment. Shoots of smaller plants and those in smaller patches appeared to be consumed in both mob grazing and rotational grazing when 2,4-D ester was applied. However, even the most decimated plants had shoots the following season. Once pastures are infested, long-term management plans are needed to keep *Artemisia absinthium* in check.

We found that mob grazing with cattle for 12 or 24 h in pastures where *Artemisia absinthium* was present did indeed improve *Artemisia absinthium* control of smaller plants (as measured in plant volume) with concomitant high forage utilization. Rotational grazing at lower stocking rates for 20 days (late-May through mid-June), when combined with 2,4-D application, also suppressed *Artemisia absinthium* for that growing season. Early (mid-April) rotational grazing with a summer rest resulted in much larger *Artemisia absinthium* plants and patches in the fall. We could not verify the statements that mob grazing would result in (1) an increase of two or more cm of soil per year, nor (2) a species composition change due to the intense grazing, which are two positive benefits of mob grazing often discussed in trade journal articles [15, 19, 52]. In addition, we did not assess the impact of mob grazing on animal performance, although in a single one-time grazing situation, a change in this parameter would not be

expected. Long term management plans are needed for *Artemisia absinthium*, as all *Artemisia absinthium* patches observed after the first grazing season produced shoots the year following grazing, regardless of the amount of grazing or trampling damage that was sustained.

Acknowledgements

Nomenclature

Cattle   *Bos taurus* L.

Absinth wormwood   *Artemisia absinthium* L.

Author details

Heidi Reed[1]*, Alexander Smart[2], David E. Clay[1], Michelle Ohrtman[1] and Sharon A. Clay[1]

*Address all correspondence to: hxm5183@psu.edu

1 South Dakota State University Department of Agronomy, Horticulture and Plant Science, Brookings, South Dakota, USA

2 South Dakota State University Department of Natural Resource Management, Brookings, South Dakota, USA

References

[1]   DiTomaso JM. Invasive weeds in rangelands: Species, impacts, and management. Weed Science. 2000;**48**:255-265

[2]   Pimentel D, Zuniga R, Morrison D. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics. 2005;**52**:273-288

[3]   Popay I, Field R. Grazing animals as weed control agents. Weed Technology. 1996;**10**: 217-231

[4] Plant Protection Act. 7 U.S.C. 7701 et seq. 114 stat. 438 [Internet]. 2000. Available from: http://www.aphis.usda.gov/plant_health/plant_pest_info/weeds/downloads/PPAText.pdf [Accessed: April 13, 2018]

[5] Ohlenbusch PD, Towne G. Rangeland Weed Management. KState Bulletin, MF-1020 [Internet]. 1991. Available from: www.bookstore.ksre.ksu.edu/pubs/mf1020.pdf [Accessed: April 13, 2018]

[6] Sellers BA, Ferrell JA. Weed Management in Pastures and Rangeland—2017. University of Florida IFAS Extension [Internet]. 2017. Available from: SS-AGR-08.edis.ifas.ufl.edu/wg006 [Accessed: June 30, 2017]

[7] Frost RA, Launchbaugh KL. Prescription grazing for rangeland weed management: A new look at an old tool. Rangelands. 2003;**25**:43-47

[8] Holechek JL. Comparative contribution of grasses, forbs, and shrubs to the nutrition of range ungulates. Rangelands. 1984;**6**:261-263

[9] Bailey DW, Brown JR. Rotational grazing systems and livestock grazing behavior in shrub-dominated semi-arid and arid rangelands. Rangeland Ecology Management. 2011;**64**:1-9

[10] Senft RL, Rittenhouse LR, Woodmansee DRG. Factors influencing patterns of cattle grazing behavior on shortgrass steppe. Journal of Range Management. 1985;**38**:82-87

[11] Fishel F. Plants Poisonous to Livestock. Columbia, MO: University of Missouri Extension; 2001. p. G-4970

[12] Crider FJ. Root-growth stoppage resulting from defoliation of grass. U.S. Dept. Agr. Tech. Bull. 1102.1955.23 pg

[13] Frost WE, Smith EL, Ogden PR. Utilization guidelines. Rangelands. 1994;**6**:256-259

[14] Savory A, Butterfield J. A commonsense revolution to restore our environment. In: Holistic Management. 3rd ed. Washington, DC: Island Press; 2016. 552pp. ISBN: 9781610917438

[15] Gordon K. Mob Grazing 101. Herford World [Internet]. 2011. Available at: www.Herford.org; hereford.org/static/files/0111_MobGrazing.pdf [Accessed: December 15, 2017]

[16] Barnes MK, Norton BE, Maeno M, Malechek JC. Paddock size and stocking density affect spatial heterogeneity of grazing. Rangeland Ecology & Management. 2008;**61**:380-388

[17] Pleasants AB, Shorten PR, Wake GC. The distribution of urine deposited on a pasture from grazing animals. Journal Agricutral. Sciences. 2006;**145**:81-86

[18] Frank DA, McNaughton SJ. Evidence for the promotion of aboveground grassland production by native large herbivores in Yellowstone National Park. Oecologia. 1993;**96**:157-161

[19] Thomas HS. Ranchers Sing the Praises of Mob Grazing of Cattle. Beef Magazine [Internet] 2012. February 28, 2012. Available from: http://www.beefmagazine.com/pasture-range/ranchers-sing-praises-mob-grazing-cattle [Accessed: March 03, 2018]

[20] McCartney DH, Bittman S. Persistence of cool-season grasses under grazing using the mob-grazing technique. Canadian Journal of Plant Science. 1994;**74**:723-728

[21] Senft RL. Hierarchical foraging models: Effects of stocking and landscape composition on simulated resource use by cattle. Ecological Modeling. 1989;**46**:283-303

[22] Maw MG, Thomas AG, Stahevitch A. The biology of Canadian weeds. 66. *Artemisia absinthium* L. Canadian Journal of Plant Science. 1985;**65**:389-400

[23] Myer H. Mob grazing as a perennial weed management tool in South Dakota grazing-lands [MS thesis]. Brookings, SD: SDSU; 2015, p. 141

[24] Anonymous. 2, 4-D Ester 4. Available from: http://www.cdms.net/LDat/ld 40L006.pdf [Accessed: November 14, 2014]

[25] Harmoney KR, Moore KJ, George JR, Brummer EC, Russell JR. Determination of pasture biomass using four indirect methods. Agronomy Journal. 1997;**89**:665-672

[26] Barnhart SK. Estimating Available Pasture Forage [Internet]. Iowa State Univ. Extension. 2009. PM 1758. https://store.extension.iastate.edu/Product/Estimating-Available-Pasture-Forage-PDF

[27] Grazing Stick Instruction Manual. The Samuel Roberts Nobel Foundation [Internet]. 2007. Available at: http://www.noble.org/ag/forage/grazingstick/index.html [Accessed: April, 2018]

[28] Steel RGD, Torrie JH. Principles and Procedures of. Statistics. 2nd ed. New York: McGraw-Hill, Inc; 1980. 633p. ISBN: 0-07-060926-8

[29] Anderson VJ, Briske DD. Herbivore-induced species replacement in grasslands: Is it driven by herbivory tolerance or avoidance? Ecological Applications. 1995;**5**:1014-1024

[30] Fuhlendorf SD, Engle DM. Restoring heterogeneity on rangelands: Ecosystem management based on evolutionary grazing patterns. Bio Science. 2001;**51**:625-632

[31] Manske LL. General Description Of Grass Growth And Development And Defoliation Resistance Mechanisms. Range Management Report DREC 98-1022. Dickinson, North Dakota: NDSU Dickinson Research Extension Center; 1998. 12p

[32] Nishica T, Shimizu N, Ishida M, Onoue T, Harashima N. Effect of cattle digestion and of composting heat on weed seeds. Japan Agricultural. Research Quarterly. 1998;**32**:55-60

[33] Rahimi S, Mashhadi HR, Banadaky MD, Mesgaran MB. Variation in Weed Seed Fate Fed to Different Holstein Cattle Groups. PLoS ONE. 2016;**11**(4):e0154057. https://doi.org/10.1371/journal.pone.0154057

[34] Stevens OA. Flowering dates of weeds in North Dakota. North Dakota Agricultural Experiment Station Bimonthly. Bulletin. 1956;**18**:209-213

[35] Kohl MT, Krausman PR, Kunkel K, Williams DM. Bison versus cattle: Are they ecologically synonymous? Rangeland Ecology Management. 2013;**66**:721-731

[36] Harker KN, Baron VS, Chanasyk DS, Naeth MA, Stevenson FC. Grazing intensity effects on weed populations in annual and perennial pasture systems. Weed Science. 2000;**48**:231-238

[37] Hart RH, Clapp S, Test PS. Grazing strategies, stocking rates, and frequency and intensity of grazing on western wheatgrass and blue grama. Journal of Range Management. 1993;**46**:122-126

[38] Isbell F, Calcagno V, Hector A, Connolly J, Harpole WS, Reich PB, Scherer-Lorenzen M, Schmid B, Tilman D, van Ruijven J, Weigelt A, Wilsey BJ, Zavaleta ES, Loreau M. High plant diversity is needed to maintain ecosystem services. Nature. 2011;**477**:199-202

[39] Deak A, Hall MH, Sanderson MA. Grazing schedule effect on forage production and nutritive value of diverse forage mixtures. Agronomy Journal. 2009;**101**:408-414

[40] Laliberte E, Lambers H, Norton DA, Tylianakis JM, Huston MA. A long-term experimental test of the dynamic equilibrium model of species diversity. Oecologia. 2013;**171**:439-448

[41] Dabaan ME, Magadlela AM, Bryan WB, Arbogast BL, Prigge EC, Flores G, Skousen JG. Pasture development during brush clearing with sheep and goats. Journal of Range Management. 1997;**50**:217-221

[42] Sahlu T, Dawson LJ, Gipson TA, Hart SP, Merkel RC, Puchala R, Wang Z, Zeng S, Goetsch AL. ASAS Centennial Paper: Impact of animal science research on United States goat production and predictions for the future. Journal of Animal Science. 2009;**87**:400-418

[43] Lupton CJ. ASAS Centennial Paper: Impact of animal science research on United States sheep production and predictions for the future. Journal of Animal Science. 2008;**86**:3252-3274

[44] 2017 State Agriculture Overview, South Dakota [Internet]. Available from: https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview [Accessed: April 12, 2018]

[45] Carey JH. *Artemisia absinthium*. In: Fire Effects Information System [Internet]. USDA, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. 1994. Available from: www.invasive.org/weedcd/pdfs/feis/Artemisiaabsinthium.pdf [Accessed: November 22, 2017]

[46] Eckardt N. Element Stewardship Abstract for *Artemisia absinthium*. Arlington, Virginia: The Nature Conservancy. 1987. Available from: www.invasive.org/weedcd/pdfs/tnc-weeds/arteabs.pdf [Accessed: November 14, 2017]

[47] Lym R, Messersmith C, Dexter A. Absinth Wormwood Control [Internet]. North Dakota State University Extension. 2013. W-838

[48] Lacey JR, Sheley RL. Leafy spurge and grass response to picloram and intensive grazing. Journal of Range Management. 1996;**49**:311-314

[49] Lym RG, Sedivec KK, Kirby DR. Leafy spurge control with angora goats and herbicides. Journal of Range Management. 1997;**50**:123-128

[50] Moechnig M, Deneke DL, Wrage LJ, Rosenberg M. Weed Control: Pasture and Range [Internet]. South Dakota State University Extension Service. 2013

[51] Holechek JL, Pieper RD, Herbel CH. Range Management: Principles and Practices. 6th ed. Upper Saddle River, NJ: Pearson/Prentice Hall; 2004. 607p. ISBN-13: 978-0130474759

[52] Hancock D. [Internet] Is Mob Grazing as Effective as we Thought? On Pasture. Availableat: https://onpasture.com/2017/11/06/is-mob-grazing-as-effective-as-we-thought/2017 [Accessed: April 12, 2018]