Agriculture, Ecosystems and Environment 149 (2012) 30–36

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Impacts of winter hay feeding on pasture soils and plants

Joao Paulo Flores, Benjamin Tracy*

Dept. Crop and Soil Environmental Sciences, Smyth Hall (0404), Virginia Tech, Blacksburg, VA 24061, United States

ARTICLE INFO

Article history:
Received 14 October 2011
Received in revised form 6 December 2011
Accepted 13 December 2011
Available online 11 January 2012

Keywords:
Pastures
Hay feeding
Forage production
Soil fertility
Winter grazing

ABSTRACT

In temperate regions, feeding livestock year round on pasture is usually limited by weather conditions and livestock must be fed hay, or other stored feeds, at least part of the year when pasture forage runs out. On many farms, hay must be fed during winter and hay feeding is typically confined to pastures that are sacrificed for this purpose. The concentrated use of pasture during winter hay feeding could negatively impact subsequent forage production from soil compaction and possibly create water quality degradation from manure runoff. In 2008, we initiated a field experiment to address how winter hay feeding on pasture might have affected forage and soil variables in VA, USA. Variables were compared between 12 paired pastures each with and without hay feeding sites. Forage accumulation, forage mass, nutritive value and plant species composition along with soil penetration resistance, soil respiration and soil nutrient concentrations were monitored for 2 years. The presence of winter hay feeding sites in pastures had neutral to positive effects on forage productivity and forage nutritive value. Hay feeding pastures were not weedier than control pastures as we predicted, and they did contain more white clover through the grazing season ($P < 0.05$), which may have benefited forage production and nutritive value. As expected, soils from winter hay feeding pastures were more compacted compared with pastures without winter use. Soil compaction did not negatively affect forage production or soil respiration, however. By the end of this study, soil P, K and organic matter concentrations were 59%, 55% and 10% higher, respectively, in hay feeding pastures compared with control pastures. Our findings suggest that well-managed hay feeding in winter could benefit pasture forage production. Moreover, strategic placement of hay feeding sites around farm could be used as a management tool to improve land productivity though nutrient inputs and introduction of legumes into pasture.

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1. Introduction

Grazing animals play a major role in the recycling and distribution of nutrients within pasture (Haynes and Williams, 1993). It is well documented that soil in areas of livestock concentration associated with water, shade or feeding sites accumulate nutrients from manure and urine depositions (West et al., 1989; Mathews et al., 1994; Franzluebbers et al., 2000). Areas of concentrated animal use also can become compacted and denuded of vegetation so nutrient and/or pathogen losses to the environment may be expected (Sharpley et al., 1987; Mawdsley et al., 1995; Hubbard et al., 2004; Owens and Shipitalo, 2009). The uneven distribution of soil nutrients also has important implications for pasture fertility as areas far from animal concentration areas could become increasingly nutrient limited over time. In low input pasture systems, management of livestock to distribute nutrients more equally across pasture could be an important management method that can be used to help sustain high forage production without reliance on external fertilizer inputs.

In temperate regions, feeding livestock year round on pasture is usually limited by weather conditions and livestock must be fed hay, or other stored feeds, at least part of the year when pasture forage runs out. This time frame usually corresponds with winter, but may apply to summertime if drought conditions become severe. Compared with other livestock concentration areas, feeding sites, in particular, have major effects on pasture soils because of the additional nutrients deposited as manure and feed wastes (Sigua and Coleman, 2006). In fact, Sanderson et al. (2010) found that feeding areas accounted for more disturbed pasture area than other concentration areas associated with water, gates and shade sources. In winter, when soils are frequently wet, hay feeding areas can become heavily disturbed and compacted from trampling by livestock. When many livestock are confined to feeding areas for long durations, the buildup of manure on compacted soils also may contribute to water quality problems if soil nutrients, sediments and fecal pathogens are washed into surface waters from heavy rain or snow melt (Warren et al., 1986; Owens and Shipitalo, 2009; Boyer and Kuczynska, 2010). Other problems can arise from trampling

* Corresponding author.
E-mail address: bftracy@vt.edu (B. Tracy).

0167-8809/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.agee.2011.12.009

and soil disturbance that may create focal points for weed invasion (Renne and Tracy, 2007) or from hay and manure wastes that provide habitat for serious insect pests like the stable fly *Stomoxys calcitrans* (L.) that afflict cattle (Broce, 2005).

Although most impacts associated with concentrated feeding sites are assumed to be negative, this may not always be the case. For example, some studies have shown that soil compaction from livestock trampling may be short-lived, and that recovery to pre-grazed condition can occur in as little as 30 days (Drewry et al., 2004; Drewry, 2006; Cournane et al., 2011). Moreover, if managed properly, nutrient inputs from livestock waste and feed could be used to build soil organic matter and overall fertility. Given the environmental importance and ubiquitous presence of feeding sites on livestock farms, more information on their impacts would be useful to ensure they are managed to limit negative effects in pasture soils and forage. In 2008, we initiated a field experiment to address this issue in VA, USA. Our specific objectives were to evaluate how winter hay feeding would affect: (1) plant variables that included forage mass and accumulation, forage nutritive value, and sward species composition, and (2) soil variables that included penetration resistance as a proxy for soil compaction, soil respiration, and nutrient concentrations. A secondary objective sought to estimate the nutrient import into pasture from hay and manure recycling during the winter feeding phase. We hypothesized that hay feeding sites would reduce forage availability and soil respiration due to soil compaction and increase weediness because of greater soil disturbance. We expected that the high manure and urine inputs in hay feeding sites would increase soil P and K concentrations, but we did not expect to detect significant differences in organic matter within the time frame of this study.

2. Material and methods

2.1. Study site

The experiment was carried out at Virginia Tech Shenandoah Valley Agricultural Research and Extension Center (Steeles Tavern VA; 37°55′55″). Soils at the site were Frederick-Christian silt loams, fine, mixed, semiactive, mesic Typic Paleudults. Climate is considered temperate with mean air temperature of 17 °C ranging from 4.7 °C in January to a high of 28.5 °C in July. Precipitation at the site predominately falls as rain with an annual mean of 987 mm and peaking between May and September (Southeast Climate Center, 2010). The experiment presented in this paper was part of a larger grazing study that began in 2008 to evaluate different grazing systems used to produce pasture-raised beef. The study involved rotational grazing of cow-calf pairs from April to September on tall fescue (*Festuca arundinacea* Schreb.) based pasture. Cow-calf pairs (n = 7 or 8 per group) were assigned to one of 12 grazing systems that each had 8 or 9 pastures (mean pasture area 0.8 ha). After weaning, cows then grazed a subset of pastures that had been stockpiled for winter grazing. The winter grazing on stockpiled tall fescue usually lasted from November to January. From January to mid-April, cows were fed hay and one pasture in each of the 12 grazing systems was designated for this purpose. The 7 or 8 cows assigned to each grazing system were confined to the designated hay feeding pasture and allowed access to hay placed in open top, round bale feeders. In addition to hay, cows could also graze residual grass biomass within the pasture. Winter stocking rates in hay feeding pastures averaged 9 animal units (AU)/ha, where 1 animal unit is equivalent to 454 kg. The same 12 hay feeding pastures were used starting in winter 2008, 2009 and 2010. Except for winter overseeding of red and white clover in 2009, the pastures received no external inputs during the course of this study.

This study used a paired plot approach to evaluate effects from hay feeding on pasture variables. Each hay feeding pasture (n = 12) was paired with an adjacent pasture that had no hay feeding area. Areas under and within the immediate vicinity of hay rings (within 2 m) were excluded from sampling. These heavily impacted areas accounted for about 5% of the pasture area and were denuded of vegetation from the high amount of hay waste that covered the soils. No comparable area could be sampled in the control pastures so areas directly under hay feeding rings were not sampled.

2.2. Forage variables

Mean herbage mass, herbage accumulation, and forage nutritive value were measured 2009 and 2010 in hay feeding (HF) and control pastures with no hay feeding (NHF). Herbage mass was estimated once a month from April through November. Forage was harvested within a 0.75 m × 3.5 m strip using a forage harvester (Swift Forage Harvester, Swift Current SK, Canada) attached to a tractor. The harvester was equipped with a balance that allowed us to weigh the samples in the field. From that sample, a subsample was taken and dried in an air forced oven (60 °C), for at least 48 h. After that, samples were weighed and the dry matter content was calculated. The dried samples were then sent to the Ruminant Nutrition Laboratory at Virginia Tech University for forage nutritive value analysis of crude protein (CP), neutral digestible fiber (NDF) and acid digestible fiber (ADF) using standard methods (Goering and Soest, 1970; Perkin Elmer, 1999; AOAC, 2000).

Forage accumulation was measured using three wire cages (1.2 m × 1.2 m) established in each pasture to exclude cattle. Forage was allowed to accumulate in exclosures from April to July and then harvested within a 0.5 m × 0.5 m quadrat. Samples were dried in an air forced oven (60 °C), for at least 48 h and weighed. Nutritive value analysis was not done on the herbage accumulation samples.

Plant species composition was accessed in October 2009, April and November 2010. Evaluations were made in 10 random locations in each plot using a 0.5 m × 1.0 m quadrat. Percent ground cover was estimated for the following species: tall fescue (*F. arundinacea* Schreb), blue grass (*Poa pratensis L.*), orchardgrass (*Dactylis glomerata L.*), white clover (*Trifolium repens L.*), and red clover (*Trifolium pratense L.*). Additional species were grouped together and classified as weeds.

2.3. Soil variables

Soil variables measured in the paired pastures included soil nutrient concentration, soil respiration and penetration resistance as a proxy for soil compaction. Soil nutrient concentrations had been monitored in all pastures within the larger grazing system experiment since 2007. We used these samples from the respective paired pastures to evaluate changes in soil nutrient concentrations since 2007 (pre hay feeding). Soil samples for nutrient concentration analysis were taken each year from 2007 until 2010. Eight samples, 20 cm deep, were taken per pasture with a soil probe (2.5 cm diameter). Subsamples were mixed in a bucket to obtain a composited sample. Soil samples then were analyzed for pH, available P and K, and exchangeable Ca, and Mg at the Virginia Tech Soil Testing Laboratory. Water pH was analyzed using a TPS Pty Ltd., model WP-80D, Dual pH–mV and temp. meter. Phosphorus, K, Mg and Ca concentrations were analyzed using an ICP-AES (Inductively Coupled Plasma – Atomic Emission Spectrometer) from a Mehlich 1, 0.05 N HCl in 0.025 N H_2SO_4 extracting solution. In 2010, soil organic matter content was evaluated using a modified Walkley–Black method.

Measurements of soil respiration began in late April 2009. To measure respiration, PVC rings (20 cm diameter and 12 cm height), were inserted into the soil (3–4 cm deep) within cattle exclosures

Table 1
Mean available forage or herbage mass in 2009 and 2010 for hay feeding (HF) and no hay feeding areas (NHF). Table includes *P*-value for comparison of the treatments (HF and NHF) in each month and year. Bonferroni adjustment *P* = 0.0143.

Month	2009			2010		
	HF (kg ha^{-1})	NHF (kg ha^{-1})	*P*-Value	HF (kg ha^{-1})	NHF (kg ha^{-1})	*P*-Value
May	1832	2263	0.2808	1982	2819	0.0808
June	2044	1778	0.5375	3742	3160	0.1930
July	2231	2188	0.8421	2022	2307	0.6397
August	2480	2122	0.0334	2390	2849	0.3373
September	2364	1758	0.1679	2295	2147	0.8086
October	3494	3042	0.5803	1679	1769	0.8645
November	3443	2420	0.1180	1470	1471	0.9986

used to measure the herbage accumulation. Soil CO_2 flux was measured within those PVC rings from May through November, using a 20 cm survey chamber and a LI-8100 Automated Soil CO_2 Flux System (LI-COR Bioscience, Lincoln, Nebraska). Mean chamber offsets for 2009 and 2010 were 7.6 cm and 8.3 cm, respectively. Soil CO_2 fluxes were measured once a month, taking one 90 s measurement per PVC ring and with a purge time of 45 s between each ring.

Soil penetration resistance (SPR) was evaluated in March 2009 and 2010, near the end of the hay feeding period using a FieldScout SC-900 Soil Compaction Meter (Spectrum Technologies, Inc., Plainfield, IL). Measurements were taken in 10 points per pasture and SPR recorded every 2.5 cm from the soil surface to 30 cm depth. Four soil samples, 0–30 cm depth, were taken per pasture to determine soil moisture. Soil samples were weighed, and then put in air forced oven, for at least 48 h at a temperature of 105 °C. In the sequence, samples were weighed again and soil water content was calculated.

2.4. Nutrients in hay and manure

We estimated the nutrient imports to hay feeding pastures that came from hay and manure over winter 2008–2009. Before feed out, each hay bale was weighed and one grab sample was taken for forage nutritive value analysis (data not shown). Manure was collected within four 0.5 m × 1.0 m quadrats in hay feeding pastures. Sampling was stratified to collect manure within at 3, 6, 9, and 12 m intervals from the hay ring. All manure was removed within each quadrat down to mineral soil, weighed and a subsample dried for at least 48 h at a temperature of 60 °C to determine dry weight mass. One hay nutritive value sample and a manure subsample from each pasture (*n* = 12) were randomly selected for nutrient analysis. Manure samples were analyzed for total N, organic N, ammonium-N, P as P_2O_5 and K as K_2O and hay samples were analyzed for N, P, K, Ca, and Mg. Both manure and plant samples were analyzed in commercial testing lab (A&L Eastern Laboratories, Richmond, VA). To estimate the nutrient imports to hay feeding pastures, we multiplied nutrient concentration by the mean amount of hay fed out over the winter (corrected to 15% moisture).

2.5. Statistical analysis

We used the GLM procedure of SAS (SAS Institute, 2008) using a model that included month, year, pasture treatment and their interactions. Except for the soil penetration resistance, the data were analyzed by using use the difference between the two plots to compare treatment effects for each variable. A repeated measures technique was used to account for multiple sampling points (months and years). The level of significance was considered $\alpha = 0.10$. Due to multiple comparisons among months, we also report the Bonferroni adjustment for significance (α/n; α = level of significance and n = number of months or years on the comparison). Soil penetration resistance data were $\log_{10}$ transformed. Data for each year were analyzed using the GLM procedure of SAS using the model below. Previous tests showed no significant effect on adjusted R^2 by adding the interaction term to the model so we left those terms out of the model.

$$Y_{ijk} = \mu + T_i + D_j + B_k + E_{ijk}$$

where T = treatment (i = 1, 2); D = depth (j = 1, 2,. . ., 12); B = block (k = 1–3); and E = experimental error.

Table 2
Mean values for crude protein (CP), neutral digestible fiber (NDF) and acid digestible fiber (ADF) in forage samples collected from May to November 2009 and 2010 in hay feeding (HF) and no hay feeding areas (NHF). Table includes *P*-value for comparison of variables (CP, NDF and ADF) between the treatments (HF and NHF) in each month. Bonferroni adjustment *P* = 0.0143 and *P* = 0.0167 for 2009 and 2010, respectively.

Month	CP (%)			NDF (%)			ADF (%)		
	HF	NHF	*P*-Value	HF	NHF	*P*-Value	HF	NHF	*P*-Value
2009									
May	16	14	0.0507	57	56	0.9341	36	30	0.0010
June	15	12	0.0079	57	62	0.0066	33	36	0.0177
July	13	11	0.0357	63	65	0.0588	35	35	0.4244
August	13	12	0.2584	63	66	0.1045	35	36	0.3195
September	16	15	0.7493	58	60	0.5943	31	31	0.8089
October	15	13	0.1416	57	59	0.4214	30	30	0.6649
November	14	12	0.0007	59	60	0.3921	31	31	0.5420
2010									
May	18	14	0.0737	54	58	0.1465	31	30	0.4762
June	16	10	<.0001	51	61	0.0008	30	33	0.0008
July	11	10	0.2770	65	67	0.2026	38	38	0.9205
August	15	12	0.0016	60	66	0.0220	33	35	0.1615
September	15	13	0.0204	60	62	0.0695	32	32	0.1854
October	17	15	0.1494	61	62	0.4913	31	32	0.2473

Table 3
Mean relative frequency and ground cover values for main forage species and weeds in hay feeding (HF) and no hay feeding areas (NHF). Bonferroni adjustment $P = 0.05$ for 2010.

Species	Relative frequency (%)			Relative coverage (%)		
	HF	NHF	*P*-Value	HF	NHF	*P*-Value
October 2009						
TF	98	100	0.3409	41	41	0.9929
BG	78	93	0.1902	12	12	0.9903
OG	77	77	1.000	7	5	0.3356
WC	77	72	0.7176	12	9	0.4343
RC	73	85	0.1504	10	13	0.3023
Weed	27	28	0.9188	2	1	0.5685
April 2010						
TF	100	100	–	29	43	<.0001
BG	79	85	0.3680	9	12	0.1093
OG	85	61	0.0289	8	5	0.0037
WC	89	68	0.0362	20	12	0.0265
RC	77	74	0.4362	9	14	0.0065
Weed	40	32	0.2110	2	3	0.7141
November 2010						
TF	100	100	–	39	52	0.3006
BG	83	96	0.5216	15	13	0.7461
OG	83	64	0.3268	13	7	0.3311
WC	64	36	0.0082	11	4	0.0083
RC	47	44	0.7888	2	2	0.5599
Weed	30	32	0.7163	1	1	0.9619

3. Results

Mean herbage mass did not differ between HF and NHF pastures in any consistent manner during 2009 and 2010 (Table 1). Herbage accumulation measured in exclosures was higher ($P = 0.0231$) in HF pastures (1543 g m^{-2}) compared with NHF pastures (1027 g m^{-2}) in 2009, but no differences were found in 2010 ($P = 0.1764$). Forage nutritive values (CP, NDF and ADF) were measured from the herbage mass samples during 2009 and 2010 growing seasons. Despite of statistical significance being found in just 2 months in each year, crude protein concentrations showed consistent trends to be higher in HF pastures compared with NHF pastures during the grazing season (Table 2). In terms of fiber components, NDF concentrations were usually lower in HF samples, but no trends were noted for ADF (Table 2). The sward species composition differed between HF and NHF pastures in some cases. White clover was encountered more frequently and occupied more ground cover in HF pastures in 2010 (Table 3). No other species exhibited consistent trends over the sampling dates. Weed abundance in HF and NHF pastures was did not differ in any of the sampling dates (Table 3).

Except for P and K concentrations, none of the soil fertility variables differed between pasture treatments. Phosphorus and K concentrations were not different in HF pastures compared with NHF pastures before this study started (2007). This trend continued through the next year as phosphorus concentration showed a slight decrease from 2007 compared to 2008 for both treatments, and it remained relatively constant until 2010 (Table 4). Potassium concentrations showed the same slight decline on the HF pastures in 2008, while in the NHF pastures there was a sharp decrease on K concentration and this difference between treatments persisted through the following years (Table 4). Soil organic matter content was measured at the end of the study in 2010 and HF pastures had a higher SOM content compared to the NHF pastures (Table 4). Analysis of soil penetration resistance (SPR) found significant main effects ($P < 0.0001$) for treatment, depth and block but no effect for their interactions were found. As expected, SPR increased with depth to 10 cm and was higher in HF pastures (Figs. 1 and 2). Comparing both years, trends in SPR were similar. Soil respiration rates did not differ between pasture treatments (Table 5).

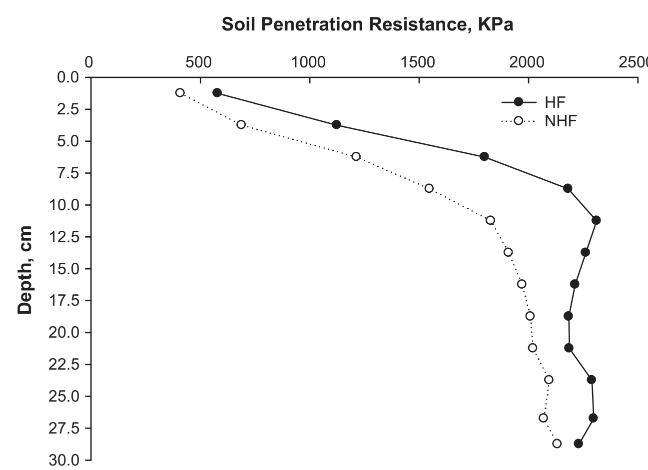

Fig. 1. Mean values for soil penetration resistance in 2009 in hay feeding (HF) and no hay feeding (NHF) areas.

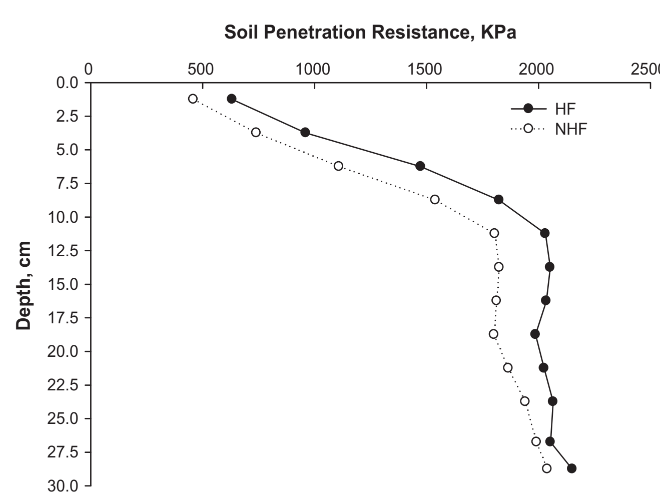

Fig. 2. Mean values for soil penetration resistance in 2010 in hay feeding (HF) and no hay feeding (NHF) areas.

Table 4
Mean values for soil chemical attributes measured in hay feeding (HF) and no hay feeding areas (NHF). Bonferroni adjustment $P = 0.025$.

Variable	2007			2008			2009			2010		
	HF	NHF	*P*-Value	HF	NHF	*P*-Value	HF	NHF	*P*-Value	HF	NHF	*P*-Value
pH	6.6	6.7	0.5995	6.8	6.8	0.6492	6.4	6.6	0.3985	6.7	6.7	0.7727
P, mg kg^{-1}	31	25	0.0743	25	19	0.1997	26	18	0.0470	27	16	0.0071
K, mg kg^{-1}	138	123	0.3714	134	84	0.0219	167	87	0.0114	142	79	0.0013
Ca, mg kg^{-1}	1154	1175	0.5339	1007	1056	0.4567	1027	1015	0.8081	887	864	0.8749
Mg, mg kg^{-1}	236	237	0.5732	194	206	0.2098	203	210	0.5223	183	173	0.4131
SOM, %	–	–	–	–	–	–	–	–	–	6.70	6.05	0.0577

Table 5
Mean values of soil CO_2 flux (μmol CO_2 m^{-2} s^{-1}) through 2009 and 2010 growing seasons (May through November) in hay feeding (HF) and no hay feeding areas (NHF).

Month	2009			2010		
	HF	NHF	*P*-Value	HF	NHF	*P*-Value
May	6	7	0.1889	–	–	–
June	11	10	0.3044	13	14	0.4954
July	8	10	0.0710	11	13	0.1967
August	9	11	0.1601	6	9	0.1967
September	3	4	0.2613	4	5	0.1346
October	3	3	0.8460	–	–	–

We also estimated nutrients imported in hay to the pastures. About 9600 kg of dry hay were fed in each pasture over the 2008/09 winter. The nutrient concentrations in the fed hay averaged 2.01% N, 0.20% P, 1.79% K, 0.42% Ca and 0.22% Mg on a dry weight basis. We also estimated that cattle deposited about 4000 kg (dry wt.) of manure on each pasture over the 2008/09 winter. Average concentrations for N, P and K in manure were 1.8%, 0.83% and 0.76%, respectively.

4. Discussion

Soils in pastures with winter hay feeding were more compacted than those without winter use, but this had no negative effect on forage production or soil respiration. Contrary to our prediction, the presence of winter hay feeding sites in pastures had neutral to positive effects on forage productivity and nutritive value. As for sward species composition, more white clover was found in hay feeding pastures and weediness did not increase as we expected. We also found that soil P and K concentrations remained higher after the beginning of this study in hay feeding pastures likely as a result of hay and manure deposition. It is not clear why we found a sharp decline in soil K concentration from 2007 to 2008 on NHF pastures. We could speculate that the soil K was being lost from the soil from leaching or runoff, but this may not make sense because the loss ceased after 2008 and K concentration remained relatively constant in the following years. The SOM content was higher on HF pastures compared with NHF pastures. Since we do not have initial SOM measurements, however, we cannot definitively claim that SOM accumulated in HF pastures. Nevertheless, SOM content was likely similar between the paired pastures at the start of this study so it may suggest that hay feeding could help rapidly build SOM.

We hypothesized that pastures with hay feeding sites would have lower forage productivity, and soil respiration rates due to soil compaction. Although soils in hay feeding pastures exhibited greater penetration resistance, this compaction had no measurable negative effect on herbage accumulation, herbage mass or soil respiration. Many studies have evaluated the effects of livestock on soil and pasture properties, and it has been well established that intensive grazing and associated trampling can compact soils by reducing soil pore space and increasing bulk density especially if grazing occurs during wet winter conditions (Greenwood and McKenzie, 2001; Drewry et al., 2004; Drewry, 2006). The magnitude of relationship between soil damage and stocking rate reported in the literature varies among studies, however. This variation may due to differences in the soil attributes measured (e.g., soil bulk density, infiltration capacity, porosity or soil type), the methods by which grazing intensities were simulated/produced, topography, climate, stocking management, and differences in the duration of experiment and observations (Bilotta et al., 2007).

While our PR measurements confirmed that pasture soils with hay feeding areas were more compacted than control pastures, most PR measurements did not exceed 2000 kPa, which is considered the threshold where compaction can adversely affect plant growth (Taylor et al., 1966) (Fig. 1). Soil respiration reflects net CO_2 production of a soil that includes respiration of roots and mineralization of organic matter. We measured soil respiration because soil compaction from machine traffic or cattle trampling has been shown to reduce soil respiration by reducing pore space and limiting O_2 diffusion (Conlin and van den Driessche, 1996, 2000; Shestak and Busse, 2005). Reduced soil respiration also may indicate less microbial activity and anaerobic conditions, both of which could negatively affect forage production. Respiration measures taken in 2009 and 2010, however, indicated no adverse effects from winter hay feeding in these areas. The moderate soil compaction and lack of response in soil respiration suggests that presence of cattle during the winter had relatively minimal effects on soil physical properties.

That the presence of winter hay feeding sites had no negative effects on forage production could be related to several factors. First, the hay feeding pastures had well established sods prior to their use as winter hay feeding sites. During the growing season, pastures in this experiment were grazed rotationally at a moderate stocking rate. This management resulted in good grass coverage, and associated root system, that often exceeded 90% of the ground cover. A well-developed root system helps with formation and stabilization of soil aggregates, and can help cushion treading damage from cattle and allow soils to recover from compaction (Teague et al., 2011). Moreover, many studies suggest that damage done to soil physical properties can be reversed by natural processes like freeze–thaw and wet–dry cycles, earthworm activity and root penetration (Dexter, 1991; Drewry, 2006; Greenwood and McKenzie, 2001). In our study, it is possible that the moderate soil compaction measured in the spring could have been alleviated by some, if not all, of these processes. The fact that soil PR values did not worsen from 2009 to 2010 lends some support to this hypothesis.

The generally positive effects on forage production may also reflect better soil fertility as hay feeding pastures had higher soil concentrations of P, K and SOM. The maintenance or increase in the concentrations of these nutrients on the HF pastures was probably related to the cycling of nutrients present on hay waste, urine and manure, deposited in higher amounts in the HF pastures during winter. Although K is mostly excreted in urine and subject to leaching loss (Kayser and Isselstein, 2005), studies have shown that it can accumulate in areas where animals congregate like waters, feeders or shade areas (Schomberg et al., 2000; Mathews et al., 1994). Owens et al. (2003) also found that hay waste was the major source of P and K in paddocks used for winter feeding.

Forage from the hay feeding pastures tended to have higher crude protein (CP) and lower fiber concentrations than control pastures especially early in the spring. The higher CP concentrations probably resulted from greater mineral N availability in soils as a consequence of manure and urine depositions (Day and Detling, 1990; Haynes and Williams, 1993). We estimated that the hay feeding pastures received 50–60 kg N ha^{-1} from manure depositions that control pastures did not receive and probably as much N from urine depositions. The intensive grazing during winter also removed much of the senescent leaf and stem material from hay feeding pastures. As a consequence, forage samples collected in the spring have virtually all green plant material, while forage samples from paired pastures had both green and dead leaf and stem material remaining from the previous season. This difference might be reflected in the lower fiber (NDF) concentrations measured in the hay feeding pastures early in the season. Higher nutritive value indices may also be related to the greater white clover abundance (Frame, 2005; Mourino et al., 2003), which was reported in 2010. Close grazing during winter in the hay feeding pastures probably benefited clover establishment as removal of residual vegetation should help increase clover germination and intensive winter grazing can help reduce grass competition in spring (Springer, 1997; Cuomo et al., 2001; Guretzky et al., 2004).

We hypothesized that hay feeding pastures would show increased weed abundance because of greater soil disturbance and possibly more weed seed inputs from hay and manure deposition. No evidence was found to suggest that winter hay feeding and concentration of livestock in these pastures increased weed abundance, however. Some weeds colonized the heavily disturbed areas directly under the hay feeding rings, but 2–3 m beyond the ring, where we sampled, showed no increase in weediness compared with control pastures. Renne and Tracy (2007) found that more weeds colonized a pasture after heavy treading disturbance, but this weed invasion occurred in a young pasture stand before a good sod had been established. This was not the case in our study. Pastures where hay feeding occurred were established at least 10 years. previously and as a consequence had a well-developed sod. Pastures with hay feeding sites had equivalent, if not better, forage production compared with control pastures. The vigorous forage production on hay feeding pastures likely helped reduce weed encroachment through competition (Busey, 2003; Tracy and Sanderson, 2004; Picasso et al., 2008). Hay feeding pastures also had significantly higher soil P and K concentrations compared with paired pastures. High P and K concentrations have been shown to be negatively related to weed abundance in pasture settings (Tracy and Sanderson, 2000).

Not surprisingly, hay feeding imported significant amounts of nutrients to pastures. About 9600 kg (1300 kg/cow) of dry hay was fed in each pasture over the 2008/09 winter. If we assume that approximately 80% of the N, P and K in hay were returned back to pasture in the form of manure, urine and hay waste (Russelle, 1992; Haynes and Williams, 1993), the winter hay feeding was equivalent to an approximate addition of 180, 20 and 175 kg ha^{-1} of N, P and K, respectively. We estimated that manure deposition alone recycled approximately 58, 26 and 24 kg ha^{-1} of organic N, P and K, respectively. It should be noted that we did not sample heavily impacted areas immediately within the hay ring feeding zone were considerable hay and manure were deposited so these values should be considered conservative estimates. Of course, not all of these nutrients would be readily available for plants immediately as these figures largely represent organically bound nutrients. Nevertheless, hay feeding represents a significant and valuable nutrient input to pasture.

Since 2004, US fertilizer prices for nitrogen (urea), phosphate and potassium have increased 48%, 58% and 70%, respectively (USDA-NASS, 2011). If these prices continue to rise, livestock producers may need to think about ways to use these imported nutrients in hay more effectively by spreading out, or rotating, hay feeding areas around farm. Also, because of potential detrimental environmental impacts from soil P buildup and possible adverse animal health issues related to excessive K in forages that may interfere with Mg uptake in the animal and lead to grass tetany (Grunes and Welch, 1989), it will be important for livestock producers to maintain soil nutrients in balance with forage needs. Frequent soil tests on hay impacted areas would be an important tool in assessing nutrient buildup in soils.

5. Conclusions

Our findings suggest that hay feeding in winter could benefit forage production, forage nutritive value and legume content in pastures. Given the amount of valuable nutrients that are imported to pastures from hay feeding, we believe that strategic use of these feeding areas could be used to improve land productivity. For example, moving small hay feeding sites every 2 years around farm, perhaps in a rotational manner, could spread out nutrient imports and reduce the possibility of environmental degradation provided that feeding areas are not overused and buffered from environmentally sensitive areas. This management approach could benefit farms where pastureland has been degraded from years of high grazing pressure and lack of fertilization. Despite the overall positive effects we documented on pasture variables in this study, more research is needed on hay feeding sites to document their indirect effects on air (e.g., denitrification), water sources (e.g., leaching, fecal pathogens) before such practices are widely adopted by livestock producers.

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