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Hay Rake-Type Effect on Ash and Forage Nutritive Values of Alfalfa Hay

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ABSTRACT

High levels of ash content are problematic in hay since ash provides no nutritional benefit to livestock. Hay raking may impact ash content, but the effect of different hay rake types on ash content is unknown. The objectives were to determine the effect of rake type on ash content and forage nutritive values of alfalfa (*Medicago sativa* L.) hay. Replicated trials were conducted on two cuttings of alfalfa in Minnesota, Pennsylvania, and Wisconsin. During raking, two swath rows were combined using one of the following rake types: wheel, sidebar, rotary, or merger. Samples were collected during the four phases of hay harvest: standing forage, post-cut, post-raked, and post-baled or chopped and analyzed for ash content and forage nutritive values. Ash content was different in five of the six sites-cuttings post-raking ($P \leq 0.05$). The hay merger and sidebar rake resulted in the least amount of ash (90–136 g kg^{-1}) while the wheel rake (100–153 g kg^{-1}) resulted in the greatest amount of ash. Differences in forage nutritive values were rarely observed due to rake type and ranged from 200–241 g kg^{-1} crude protein (CP), 374–480 g kg^{-1} NDF, and 393 to 532 g kg^{-1} neutral detergent fiber digestibility (NDFd) post-raking. First cutting alfalfa differed in relative forage quality (RFQ) post-raking where the hay merger and sidebar rake tended to result in greater RFQ values (121–165) compared with the wheel rake (114–160; $P \leq 0.05$). Using a hay merger or sidebar rake to combine swaths resulted in less ash content compared with a wheel rake; however, rake type rarely resulted in differences in forage nutritive values.

Core Ideas

- High levels of ash content provide no nutritional benefit to livestock.
- A hay merger or sidebar rake resulted in less ash content compared to a wheel rake.
- Rake type rarely resulted in differences in forage nutritive values.

Alfalfa is widely used in livestock rations and can be one of the most expensive dietary components (Rotz and Muck, 1994; Broderick, 1995; Martinson et al., 2012). Alfalfa was grown on >6.7 million hectares in 2016, producing more than 53.5 million Mg with a value of US$8.7 billion, making it one of the top four economically important crops in the contiguous 48 states (NASS, 2017a, 2017b). However, total alfalfa land area in the United States has been declining since 2013 (NASS, 2017a), which has intensified efforts to optimize yield and forage nutritive values through harvest management and storage efficiencies. Previous research has outlined best management practices for alfalfa harvest including optimizing cutting schedules, cutting height, forage drying time, and equipment settings (Sheaffer et al., 1988; Shearer et al., 1992; Rotz and Shinners, 2007; Kung et al., 2010). However, these efforts have focused mainly on the interactions between forage yield and crude protein (CP), digestible energy, and fiber fractions (Sheaffer et al., 1988; Rotz and Shinners, 2007).

Ash content includes two categories, endogenous and exogenous. Endogenous ash is defined as naturally occurring plant minerals while exogenous ash is minerals primarily associated with soil contamination. The endogenous ash content of leguminous forages averages 80 g kg^{-1} with total ash content averaging 100 g kg^{-1} (Undersander, 2010). Based on these values, most leguminous forages contain approximately 20 g kg^{-1} exogenous ash or soil contamination. Higher levels of ash content are problematic in hay since ash provides no nutritional benefit to livestock (Bertone et al., 1988; Husted et al., 2005).

Ash is a component of the non-fiber carbohydrate calculation (NRC, 2001) used to calculate total digestible nutrients (TDN), which negatively impacts the net energy value of the ration. The physiological ramifications of feeding hay with higher ash

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Abbreviations: ADF, acid detergent fiber; CP, crude protein; DE, digestible energy; DM, dry matter; DMI, dry matter intake, NASS, National Agriculture Statistic Service; NDF, neutral detergent fiber; NDFd, neutral detergent fiber digestibility; PSI, pounds per square inch; PTO, power takeoff; RFQ, relative forage quality; TDN, total digestible nutrients.

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contents are not well understood. However, researchers have theorized that excessive ash contents could be a barrier to performance in bovine, ovine, and caprine species and could negatively impact health of equines (Bertone et al., 1988; Husted et al., 2005). Excessive ash (>80 g kg^{-1}; Undersander, 2010) could be a barrier to maximizing milk and meat production because ash provides no calories. For example, a 10 g kg^{-1} increase in ash can result in a 1% decrease in TDN of the hay (Undersander, 2010). In horses, excessive ash content resulting in the ingestion of soil contamination can lead to sand colic (Bertone et al., 1988; Husted et al., 2005) and may reduce absorption of nutrients and water (Udenberg, 1979; Ragle et al., 1989).

Raking hay to facilitate drying and pick-up has been identified as a phase of haymaking that can affect the yield and quality of forage (Pitt, 1990; Rotz and Shinners, 2007). Because hay rakes may come into contact with the ground, the potential to contribute ash during the raking process exists. Rake mechanisms, function and economic value differ among hay rake types and have been summarized by Schuler and Shinners (2003). Briefly, sidebar rakes (also known as parallel-bar or Rolabar) are ground driven, but can be adjusted to have limited contact with the ground due to a powertrain (wheel belt or power take-off [PTO] options). However, a disadvantage of the sidebar rake is a limited working width. Wheel rakes are also ground driven but require contact with the ground to gather hay. These rakes are less expensive and some models allow a swath to be raked as wide as 11 m. Rotary rakes are power driven and adjustments can be made to avoid excess contact with the ground and to avoid unnecessary contact with the forage leaves. A hay merger is not classified as a rake, but still accomplishes the merging of swath rows. Mergers are power driven and can be adjusted to avoid excess contact with the ground. Although this piece of equipment can save time and labor by merging multiple swaths at once, it tends to be more costly compared with other hay rakes.

Ash content can be affected by equipment used during hay harvest; however, most research has focused on the hay cutting phase. Digman et al. (2011) determined that wide swaths, cutting heights ≥6 cm, and angled knives on hay mowers resulted in harvested forage with less ash content. Because soil disturbance is possible during hay raking, this harvest phase has a potential to affect ash content of forage; however, the effect of raking on ash content has not been evaluated. Therefore, the objectives of this research were to determine the effects of hay rake type on ash content and nutritive values of alfalfa hay, with a hypothesis that ground driven rakes would result in greater amounts of ash compared with power driven rakes.

MATERIALS AND METHODS

Replicated trials were conducted during the 2015 growing season in Minnesota (MN), Pennsylvania (PA), and Wisconsin (WI). In Minnesota (45°16′47.458″ N, 93°36′57.676″ W) and Pennsylvania (40°48′45.198″ N, 77°52′49.1016″ W), research was conducted on farms with cooperating alfalfa hay producers. In Wisconsin, research was conducted at the U.S. Dairy Forage Research Center (N43°17′52.8″, W 89°21′19.6″). Soil types at Minnesota, Pennsylvania, and Wisconsin were loamy sand, Entic Hapludolls; silty loam, Typic Hapludalfs; and silty loam, Typic Agriudolls, respectively. Targeted alfalfa maturity at cutting was 10% bloom (Kalu and Fick, 1981) with a goal of rain-free harvested hay. To examine diverse growing conditions within each location, harvest and raking occurred during the first cutting and a subsequent cutting (Table 1). The subsequent cutting included a second cutting in Pennsylvania and Wisconsin and a third cutting in Minnesota. In Minnesota, the second cutting was hampered by rainfall, necessitating the use of the third cutting. Hay fields had an alfalfa stand density of ≥500 stems per m^2 at all three locations, which were determined by counting stems in a m^2 quadrant at 16 random locations throughout the field.

To account for field variation, swath rows were assigned to a randomized complete block design with four replications and headland rows were excluded from the collection area. During each step of haymaking, forage was sampled to determine treatment effects on ash, CP, neutral detergent fiber (NDF), NDFd, and relative forage quality (RFQ). Prior to harvest, four 0.25 m^2 random samples of standing forage were hand harvested from each replicate 6 cm above the soil surface and served as the control. Alfalfa was then cut with a disc mower (Minnesota: MoCo 835, John Deere, Moline, IL; Pennsylvania: MoCo 946, John Deere, Moline, IL; Wisconsin: RD 163, Case IH, Racine, WI) using best management practices to limit ash content including use of a wide swath and maintaining cutting heights ≥6 cm (Digman et al., 2011). Post-cutting, each of the replicates were comprised of eight swath rows. Four 0.25 m^2 random samples of cut forage were hand harvested from each replicate to determine hay mower contribution to ash content and impact on forage nutritive values. When swaths reached approximately 600 g kg^{-1} DM, two swath rows in each replicate were combined using one of the following rakes; merger, rotary rake, sidebar rake or wheel rake (Table 2). Hay rakes were adjusted according to manufacturer recommendations and run at a standardized range of speed, operating width, PTO, or pounds per square inch (PSI) at each site (Table 2). Sidebar rakes were set to operate at 0.6 cm off the field surface.

Table 1. Sampling and harvest dates in Minnesota, Pennsylvania, and Wisconsin for standing (Stand), post-cut (Cut), post-raked (Rake), and post-baled or chopped (Bale) alfalfa hay in 2015.

Location	Stand	Cut	Rake	Bale
		First cutting		
Minnesota	30 May	30 May	2 June	2 June
Pennsylvania	3 June	3 June	5 June	5 June
Wiscons	18 May	18 May	19 May	21 May
		Subsequent cutting		
Minnesota	29 July	29 July	1 August	1 August
Pennsylvania	10 July	10 July	12 July	13 July
Wisconsin	30 June	30 June	3 July	4 July

Table 2. Model, working width (meters), operating speed (kilometers per hour) and power takeoff (rpm) for four rake types used to combine alfalfa swaths in Minnesota, Pennsylvania, and Wisconsin.

Rake type	Minnesota	Pennsylvania	Wisconsin
Hay merger	New Holland† H5420	Miller Pro Avalanche‡	H&S§ TWM-12
Working width, m	3.6	10.3	12.2
Operating speed, kph	12.9–16.1	12.9–16.1	12.9–16.1
PTO (rpm) or PSI	2000 psi	1000 rpm	1000 rpm
Rotary rake	Kuhn¶ GA7301	Kuhn¶ GA 4221 GTH	Kuhn¶ GA7301
Working width, m	7.4	3.2	7.4
Operating speed, kph	8	8	8
PTO, rpm	400–450	400–450	400–450
Sidebar rake	New Holland† 258	John Deere# 672	New Holland† 260
Working width, m	2.9	2.9	2.9
Operating Speed, kph	3.2–11.3	3.2–16.1	3.2–11.3
Wheel rake	New Holland† PC 1225	New Holland† 1022-10	H&S§ BF14 HC
Working width, m	7.1	6.1	8.5
Operating speed, kph	12.9–16.1	12.9–16.1	12.9–16.1

† New Holland Agriculture (New Holland, PA).
‡ Miller Pro, Art's-Way Manufacturing Co., Inc. (Armstrong, IA).
§ H&S Manufacturing Company, Inc. (Marshfield, WI).
# John Deere (Moline, IL).
¶ Kuhn North America (Brodhead, WI).

Post-raking, a tarp (0.5 m^2) was positioned under a section of the combined swaths to capture ash and other plant material that could potentially be lost during sample handling. A 15 cm wide section was subsampled from four random locations of each hay rake-type swath per replicate. When the forage dried to approximately 850 g kg^{-1} dry matter (DM), raked swaths were baled using either a small square-baler (Minnesota and Pennsylvania) or large round-baler (Wisconsin). Impending rainfall during first cutting in Pennsylvania resulted in forage being chopped for silage production. Random 250-g samples were collected post-baling using a hay corer (2 by 51 cm) or post-chopping by hand grab samples.

All samples were dried at 60°C for a minimum of 24 h. After drying, samples were ground through a 6-mm screen in a Wiley mill (Thomas Scientific, Swedesboro, NJ) followed by a 1-mm screen in a cyclone mill (UDY Corporation, Fort Collins, CO). Samples were mixed thoroughly and subsamples were analyzed for forage nutritive values using the following methods. Ash content was analyzed by igniting sample in a furnace at 600°C to oxidize all organic matter (AOAC, 1990). Ash was determined by weighing the resulting inorganic residue. Prediction equations developed for legume hay by the NIRS Forage and Feed Testing Consortium were estimated using near-infrared spectroscopy (NIRS model 6500, Foss Eden Prairie MN) to determine CP, NDF, and NDFd. The standard error of cross validation was 0.72, 1.97, and 2.1, while the R^2 was 0.72, 0.95 and 0.89 for CP, NDF, and NDFd48 (NDFd), respectively (NIRS, 2016). Relative forage quality (RFQ) was calculated using NIRS predicted values of TDN × intake calculation/1.23 (Moore and Undersander, 2002). Daily air temperature and rainfall were compiled for the experimental period of the 2015 harvest season at all locations.

All parameters were analyzed using the MIXED procedure in SAS with statistical significances set at $P \leq 0.05$ (SAS Institute, 2013). Alfalfa hay rake treatments (merger, rotary, sidebar, and wheel), crop phases (standing, cut, post-raked, and post-baled

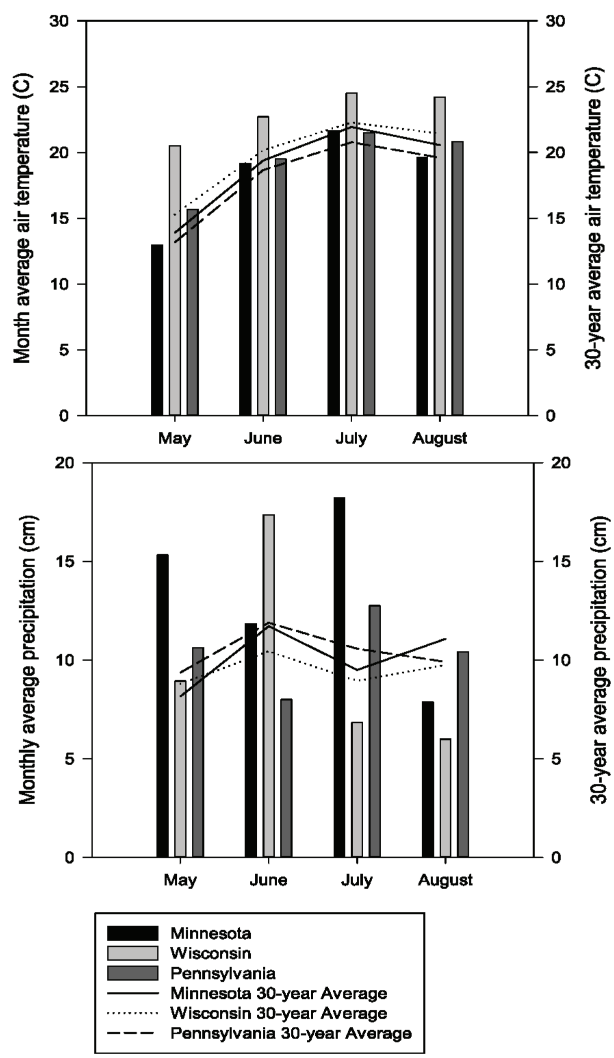

Fig. 1. Monthly average temperature (°C), average precipitation (cm), and the 30-yr average temperature and precipitation in Minnesota, Pennsylvania, and Wisconsin during the 2015 hay harvest season.

or chopped) and site-cuttings were modeled as fixed effects, and replicates were random effects. A combined analysis of forage nutritive value parameters across the three site-cuttings was attempted, but was prevented due to interactions between cutting, hay rake treatment, and site for both first ($P < 0.05$) and subsequent alfalfa cuttings ($P < 0.05$; Moore and Dixon, 2015). All forage yield and quality parameters for site-cutting, harvest phase (standing, post-cut, post-raked, and post-baled or chopped), and alfalfa harvest (first and subsequent) were analyzed separately. Change in percent ash was calculated by subtracting ash content post-raking from standing alfalfa for each hay rake type. All means were separated using pre-planned contrasts and Tukey's HSD at $P = 0.05$ (Steel et al., 1996).

RESULTS AND DISCUSSION

Weather

Mean monthly air temperature at all locations were similar or slightly higher than the 30-yr average (Fig. 1). Rainfall during May through August of 2015 was similar to the 30-yr historical average in Wisconsin. In Minnesota, greater than average rainfall was recorded in May and July while in Pennsylvania, greater than average rainfall was recorded in June compared with the 30-yr historical average. The threat of rainfall post-cutting in Pennsylvania caused researchers to chop and ensilage first cutting.

Ash Content

Ash content of standing forage ranged from 96 to 112 g kg^{-1} in Minnesota, 98 to 105 g kg^{-1} in Pennsylvania, and 94 to 104 g kg^{-1} in Wisconsin (Table 3). Greater rainfall, which can result in splashing of soil particles onto plants, combined with the sandy soil type may have contributed to the higher ash content observed in first cutting in Minnesota. Ash content of post-cut alfalfa ranged from 106 to 128 g kg^{-1} in Minnesota, 102 to 110 g kg^{-1} in Pennsylvania, and 94 to 109 g kg^{-1} in Wisconsin (Table 3). The small increase in ash content during the hay cutting phase (≤16 g kg^{-1}) reinforced that recommended best management practices including wide swaths and cutting heights ≥6 cm (Digman et al., 2011) helped to limit ash content during hay cutting.

Hay rake type affected ash content post-raking at all site-cuttings except for first cutting in Wisconsin ($P \leq 0.05$; Table 3). The wheel rake always resulted in the greatest ash content post-raking. In contrast, the hay merger and sidebar rake resulted in the least amount of ash while the rotary rake tended to result in intermediate amounts of ash. These results help confirm the generally accepted observation that different types of hay rakes result in different amounts of ash post-raking. Because wheel rakes must contact the ground to merge windrows (Schuler and Shinners, 2003), it was anticipated that this rake type would result in a greater amount of ash due to the increased opportunity to introduce soil contaminants into the forage.

Post-baling, similar trends were observed but only at three of the six site-cuttings ($P \leq 0.05$; Table 3). Using a hay merger or sidebar rake to combine swaths tended to result in less ash content compared with a wheel rake post-baling. These results can be combined with established best management practices that reduce ash content including use of wide swaths, cutting heights ≥6 cm, and angled knives on disc mowers (Digman et al., 2011). The results observed in the current study are greater than those of Kung et al. (2010) and Yoder et al. (2013) who reported ash contents of 86 and 69 g kg^{-1} in alfalfa haylage and silage. These differences could be due to local soil types, weather conditions, or harvest differences associated with haylage, silage, and hay. However, ash content of alfalfa hay post-baling or chopping observed in this study are similar to ranges reported

Table 3. Ash content of standing (Stand), post-cut (Cut), post-raked (Rake) and post-baled or chopped (Bale) alfalfa hay after first and a subsequent cutting in Minnesota, Pennsylvania, and Wisconsin in 2015. Hay was raked with a hay merger (Merger), rotary rake (Rotary), sidebar rake (Sidebar), or wheel rake (Wheel).

		Alfalfa harvests							
		Stand	Cut	Rake	Bale	Stand	Cut	Rake	Bale
Location	Rake type	First cutting				Subsequent cutting			
		g kg^{-1}							
Minnesota	Merger	112†	128†	111b‡	114b	96†	106‡	105b	113
	Rotary			136a	130ab			125ab	124
	Sidebar			135a	132ab			136a	124
	Wheel			153a	146a			138a	129
	SE	15	32	81	47	19	21	75	48
Pennsylvania	Merger	98†	102†	98b	98b	105†	110†	97ab	99
	Rotary			99b	105ab			99ab	100
	Sidebar			95b	98b			95b	102
	Wheel			106a	111a			100a	103
	SE	22	33	29	17	12	34	13	15
Wisconsin	Merger	94†	94†	90	92	104†	109†	99ab	98ab
	Rotary			97	93			100ab	97ab
	Sidebar			91	90			98b	95b
	Wheel			103	95			105a	103a
	SE	19	40	51	22	15	37	18	18

† Values represent the mean of samples (***n*** = 16) collected across the field area.

‡ Within each column, location and cutting, means without a common letter differ based on a Tukey test ($P \leq 0.05$). No letter indicates no differences were observed ($P \geq 0.05$).

by Undersander (2010) and a commercial testing laboratory (Equi-Analytical, 2016) who reported average ash values of 123 and 107 g kg^{-1}, respectively. The current results align with the research hypothesis that ground driven rakes would result in greater amounts of ash due to contact with the ground.

Changes in percent ash as a percentage of standing alfalfa are shown in Fig. 2. Compared with the standing forage, hay rake type impacted percent change in ash during both cuttings in Minnesota and the first cutting in Pennsylvania. In all three situations, the wheel rake resulted in an increase in ash content compared with the hay merger. During the subsequent cutting in Pennsylvania and both cuttings in Wisconsin, most hay rake types resulted in a decrease in percent ash when the post-raked alfalfa was compared with the standing alfalfa. Although difficult to explain, we hypothesize that as the forage dried, the soil contamination also dried and was removed during raking. Interestingly, the cutting phase only contributed ash ($P \leq 0.05$) during the subsequent cutting at all three locations (<1%, data not shown). It is well known that subsequent alfalfa cuttings result in less forage yield compared with the initial cutting (Berti et al., 2012; Sheaffer et al., 1988). We hypothesize that the lower yield resulted in greater ground exposure and drier soil conditions which may have loosened soil particles and contributed more ash in the subsequent cutting post-cut. Future research should focus on the complex interaction of forage yield, ground moisture, forage moisture, and harvest phase on ash content.

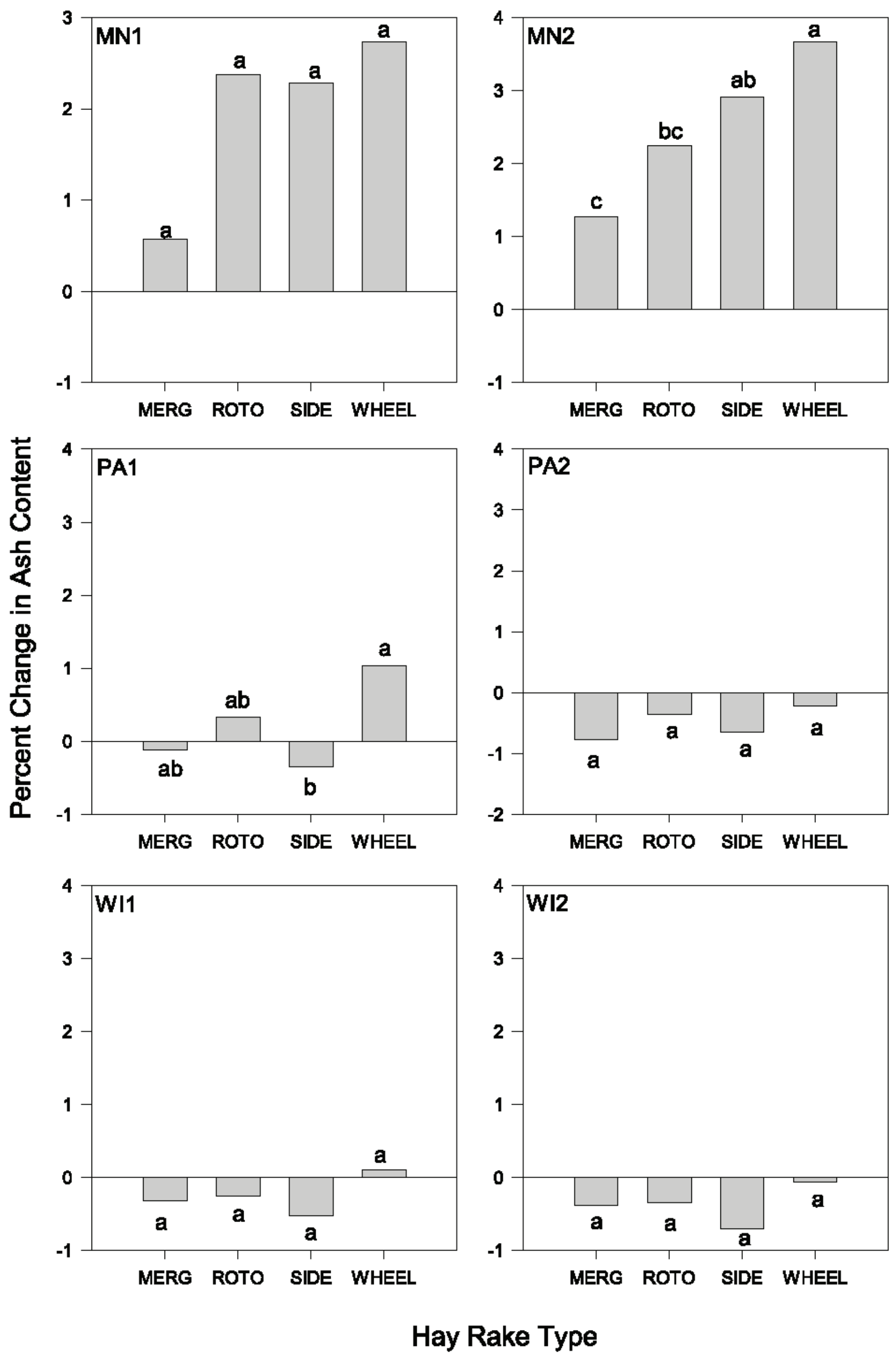

Fig. 2. Change in percent ash (dry matter, DM) as a percentage of standing alfalfa at three locations (MN: Minnesota, PA: Pennsylvania, WI: Wisconsin) and two harvests (1: First-cut, 2: Subsequent-cut) using different hay rake types (Merger, MERG; Rotary, ROTO; Sidebar, SIDE; and Wheel-rake, WHEEL). Bars sharing the same letter are not different based on Tukey HSD ($P \leq 0.05$).

Table 4. Crude protein (CP) of standing (Stand), post-cut (Cut), post-raked (Rake), and post-baled or chopped (Bale) alfalfa hay after first and a subsequent cutting in Minnesota, Pennsylvania, and Wisconsin in 2015. Hay was raked with a hay merger (Merger), rotary rake (Rotary), sidebar rake (Sidebar) or wheel rake (Wheel).

Location	Rake type	First cutting				Subsequent cutting			
		Stand	Cut	Rake	Bale	Stand	Cut	Rake	Bale
		g kg^{-1}							
Minnesota	Merger	227†	230†	221	221	233†	213†	203	216
	Rotary			215	223			208	210
	Sidebar			212	217			201	207
	Wheel			220	222			208	203
	SE	25	28	34	27	50	64	44	40
Pennsylvania	Merger	209†	207†	200	201	230†	229†	213	216
	Rotary			202	212			211	219
	Sidebar			205	208			205	216
	Wheel			203	201			208	216
	SE	33	25	39	24	17	39	30	30
Wisconsin	Merger	223†	222†	214	214b‡	255†	248†	238	240
	Rotary			218	215ab			235	236
	Sidebar			223	222a			241	232
	Wheel			213	220ab			241	240
	SE	20	27	16	30	39	73	50	30

† Values represent the mean of samples (n = 16) collected across the field area.

‡ Within each column, location and cutting, means without a common lettert differ based on a Tukey test ($P \leq 0.05$). No letter indicates no differences were observed ($P \geq 0.05$).

The ramifications of feeding livestock hay with higher ash contents are not well understood. It is thought that excessive ash contents, or values >80 g kg^{-1}, (Undersander, 2010) could be a barrier to maximizing milk and meat production and may lead to sand colic and reduce absorption of nutrients and water in horses (Bertone et al., 1988; Husted et al., 2005; Udenberg, 1979; Ragle et al., 1989). In Minnesota first cutting hay, the wheel rake resulted in 146 g kg^{-1} ash while the hay merger resulted in 114 g kg^{-1}ash post-baling. If a livestock producer fed 11 kg of hay (DM basis) containing 146 g kg^{-1} ash (or approximately 66 g kg^{-1} exogenous ash), they would be feeding 0.7 kg of soil contamination [(66 g kg^{-1} × 11 kg)/1,000 g] to their livestock compared with only 0.4 kg of soil contamination [(34 g kg^{-1} × 11 kg)/1,000 g] if the hay contained 114 g kg^{-1} ash (or approximately 34 g kg^{-1} exogenous ash) on a daily basis. Feeding 0.4 to 0.7 kg of exogenous ash on a daily basis offers no feeding value to livestock and therefore does not contribute to animal performance. Future research should explore the impact of elevated ash content on livestock health and performance.

Table 5. Neutral detergent fiber (NDF) of standing (Stand), post-cut (Cut), post-raked (Rake), and post-baled or chopped (Bale) alfalfa hay after first and a subsequent cutting in Minnesota, Pennsylvania, and Wisconsin in 2015. Hay was raked with a hay merger (Merger), rotary rake (Rotary), sidebar rake (Sidebar), or wheel rake (Wheel).

Location	Rake type	Stand	Cut	Rake	Bale	Stand	Cut	Rake	Bale
		First cutting				Subsequent cutting			
		g kg^{-1}							
Minnesota	Merger	411†	440†	393	390	364†	412†	442	427
	Rotary			410	385			435	448
	Sidebar			412	398			449	445
	Wheel			399	389			439	458
	SE	94	72	65	76	87	109	99	82
Pennsylvania	Merger	427†	427†	441	458	434†	440†	466	459
	Rotary			441	455			468	455
	Sidebar			444	454			482	457
	Wheel			452	479			480	459
	SE	105	67	47	81	49	80	59	92
	Merger	428†	435†	422ab‡	431	371†	368†	384	385
	Rotary			415ab	436			388	385
Wisconsin	Sidebar			407b	419			374	394
	Wheel			431a	428			375	383
	SE	44	72	60	62	82	117	123	61

† Values represent the mean of samples (n = 16) collected across the field area.

‡ Within each column, location and cutting, means without a common letter differ based on a Tukey test ($P \leq 0.05$). No letter indicates no differences were observed ($P \geq 0.05$).

Excessive ash content can also be problematic when purchasing hay. Using the same values as above, 1 Mg of hay containing 146 g kg^{-1} ash (or approximately 66 g kg^{-1} exogenous ash) would contain 66 kg of soil contamination compared with 34 kg of soil contamination when the ash content was reduced to 114 g kg^{-1} (or approximately 34 g kg^{-1} exogenous ash). At an average cost of US$150 Mg^{-1}, a hay buyer would be spending $9.90 Mg^{-1} [(66 kg/1,000 kg) × $150] on soil contamination on hay raked with a wheel rake compared with $5.10 Mg^{-1} [(34 kg/1,000 kg) × $150] on hay combined with a hay merger. In this case, the seller received the same price Mg^{-1} regardless of ash content; however, the buyer paid for soil contamination which has no feeding value to livestock.

Crude Protein

Crude protein values of standing alfalfa ranged from 209 to 255 g kg^{-1} across the three locations, while post-cut alfalfa ranged from 207 to 248 g kg^{-1} (Table 4). No differences in CP due to hay rake type were observed post-raking ($P \leq 0.05$), and differences in CP post-baling were only observed in Wisconsin first cutting. Although the range of CP across hay rake types in Wisconsin first cutting was minimal (214–222 g kg^{-1}), the sidebar rake resulted in a greater amount of CP compared with the hay merger ($P \leq 0.05$).

Crude protein values post-baling or chopping observed in the current study are similar to those observed by Berti et al. (2012) who reported CP ranging from 204 to 241 g kg^{-1} in alfalfa hay. Broderick (1995) and Yoder et al. (2013) observed CP ranged from 183 to 215 g kg^{-1} in alfalfa silage, similar to most results observed in the current study. However, the current CP values are slightly higher than those reported by Bosworth and Stringer (1992) who observed CP averaged 180 g kg^{-1} in alfalfa hay when harvested at a maturity similar to the current study. The minimal change in CP throughout the harvest phases is likely reflective of the short harvest window (3–5 d), lack of rainfall once cut, and best management practices that aimed to minimize leaf loss and maximize drying time.

Neutral Detergent Fiber and Neutral Detergent Fiber Digestibility

Neutral detergent fiber of the standing alfalfa ranged from 364 to 434 g kg^{-1}and from 368 to 440 g kg^{-1} post-cut across the three locations (Table 5). Differences in NDF post-raking were only observed in Wisconsin first cutting where the sidebar rake resulted in less NDF compared with the wheel rake; however, the differences were minimal (407–431 g kg^{-1}). No differences in NDF post-baling or chopping were observed. The NDF values observed in the current study are similar to Bosworth and Stringer (1992) who reported NDF of alfalfa cut at 10% bloom averaged 420 g kg^{-1} and to Yoder et al. (2013) who reported alfalfa silage ranged from 444 to 453 g kg^{-1} NDF. The current results are mostly higher than those reported by Broderick (1995) who found alfalfa silage and hay ranged from 352 to 414 g kg^{-1} and Berti et al. (2012) who reported alfalfa harvested in North Dakota ranged from 292 to 391 g kg^{-1} NDF.

The NDFd of the standing forage ranged from 394 to 496 g kg^{-1} and from 397 to 504 g kg^{-1} post-cut (Table 6). Differences in NDFd post-raking were observed in Pennsylvania first cutting and the Wisconsin subsequent cutting. However, no consistent patterns were identified. Differences in NDFd post-baling were only observed in Minnesota first cutting where the sidebar rake resulted in greater NDFd compared with the hay merger. The NDFd of the standing forage ranged from 394 to 496 g kg^{-1} and from 397 to 504 g kg^{-1} post-cut (Table 6). Differences in NDFd post-raking or baling were observed in three of the site-cuttings. In general, the sidebar rake resulted in greater NDFd, while the wheel rake tended to result in less. The NDFd observed in the current study are similar to those reported by a commercial forage testing laboratory that reported NDFd48 ranged from 416 to 527 g kg^{-1} (DairyOne, 2016).

Table 6. Neutral detergent fiber digestibility (NDFd) of standing (Stand), post-cut (Cut), post-raked (Rake), and post-baled or chopped (Bale) alfalfa hay after first and a subsequent cutting in Minnesota, Pennsylvania, and Wisconsin in 2015. Hay was raked with a hay merger (Merger), rotary rake (Rotary), sidebar rake (Sidebar), or wheel rake (Wheel).

		First cutting				Subsequent cutting			
Location	Rake type	Stand	Cut	Rake	Bale	Stand	Cut	Rake	Bale
		g kg^{-1}							
Minnesota	Merger	416†	467†	495	501b‡	496†	504†	507	515
	Rotary			475	505ab			493	483
	Sidebar			497	519a			503	532
	Wheel			496	502ab			498	507
	SE	158	94	80	44	110	149	178	102
Pennsylvania	Merger	414†	407†	410a	411	402†	397†	395	399
	Rotary			410a	421			405	405
	Sidebar			404ab	402			395	406
	Wheel			393b	393			401	402
	SE	48	60	41	74	39	50	35	37
	Merger	394†	398†	417	412	440†	457†	436b	431
	Rotary			420	416			442ab	433
Wisconsin	Sidebar			430	415			444ab	426
	Wheel			403	415			456a	432
	SE	75	136	80	28	84	80	50	61

† Values represent the mean of samples (n = 16) collected across the field area.

‡ Within a column, means without a common letter differ based on a Tukey test ($P \leq 0.05$). No letters indicate no differences were observed ($P \geq 0.05$).

Table 7. Relative forage quality (RFQ) of standing (Stand), post-cut (Cut), post-raked (Rake), and post-baled or chopped (Bale) alfalfa hay after first and a subsequent cutting in Minnesota, Pennsylvania, and Wisconsin in 2015. Hay was raked with a hay merger (Merger), rotary rake (Rotary), sidebar rake (Sidebar), or wheel rake (Wheel).

		First cutting				Subsequent cutting			
Location	Rake type	Stand	Cut	Rake	Bale	Stand	Cut	Rake	Bale
		% dry matter							
Minnesota	Merger	131†	133†	165a‡	168	189†	164†	148	154
	Rotary			151b	170			146	135
	Sidebar			155ab	167			143	151
	Wheel			160ab	167			145	139
	SE	2.2	2.3	3.5	4.4	4.6	4.8	3.4	4.8
Pennsylvania	Merger	131†	130†	124a	117ab	127†	122†	111	114
	Rotary			124a	121a			113	117
	Sidebar			121ab	116ab			106	116
	Wheel			114b	105b			107	115
	SE	4.6	3.8	2.3	4.0	2.9	3.6	3.9	2.4
	Merger	125†	123†	133ab	128	165†	172†	157	159
	Rotary			136ab	127			156	158
Wisconsin	Sidebar			143a	135			165	154
	Wheel			125b	130			166	158
	SE	2.8	4.1	3.4	2.7	5.0	8.4	3.2	7.5

† Values represent the mean of samples (*n* = 16) collected across the field area.

‡ Within a column, means without a common superscript differ based on a Tukey test ($P \leq 0.05$). No superscripts indicate no differences were observed ($P \geq 0.05$).

Hall and Mertens (2012) also reported similar to slightly higher NDFd for alfalfa hay that ranged from 476 and 590 g kg^{-1} using NDFd30. Similar to CP, the minimal change in both NDF and NDFd throughout the harvest phases is likely reflective of the short harvest window (3–5 d), lack of rainfall once cut, and best management practices that minimized leaf loss and maximized drying time.

Relative Forage Quality

Relative forage quality of the standing alfalfa ranged from 125 to 189 and from 122 to 172 post-cutting (Table 7). Differences in RFQ post-raking were only observed in first cutting alfalfa at all three locations. The wheel rake resulted in a lower RFQ compared with the hay merger ($P \leq 0.02$). Post-baling or chopping, differences ($P \leq 0.03$) were only observed in first cutting in Pennsylvania where the wheel rake resulted in a lower RFQ compared with the rotary rake. The RFQ of the post-cut or baled hay observed in the current study is mostly similar to those reported by Berti et al. (2012) when alfalfa was harvested at 30% bloom; they observed RFQ ranging from 156 and 177. Yost et al. (2011) observed a higher average RFQ of 180 when alfalfa was harvested at multiple sites in Minnesota under grower management.

Relative forage quality is a calculated index that uses estimated livestock DM intake and TDN to assess overall forage quality (Moore and Undersander, 2002; University of Wisconsin, 2013). Total digestible nutrients is a measure of the energy value in a feedstuff and is negatively impacted by ash content (NRC, 2001). In the current research, the wheel rake tended to result in the greatest ash content, while the hay merger resulted in the least amount of ash. Since ash content negatively impacts TDN and therefore RFQ, these results help to explain the differences observed in RFQ values between the wheel rake and hay merger.

CONCLUSIONS

Differences in ash content post-raking were observed between rake types in five of six site-cuttings. In general, the wheel rake resulted in the greatest amount of ash while the hay merger and sidebar rake resulted in the least amount of ash. Throughout the harvest process, CP ranged from 200 to 241 g kg^{-1}, NDF from 368 to 482 g kg^{-1} and NDFd from 393 to 532 g kg^{-1}. However, differences due to hay-rake type were rarely observed and forage nutritive values remained mostly consistent throughout the harvest process. First cutting alfalfa differed in RFQ post-raking where the hay merger and sidebar rake tended to result in greater RFQ values (121–165) compared with the wheel rake (114–160). In conclusion, using a hay merger or sidebar rake to combine swaths resulted in less ash content compared with a wheel rake; however, hay rake type rarely resulted in differences in forage nutritive values. Excessive ash content can result in reduced economic efficiencies when purchasing hay and offers no feeding value or contributions to livestock performance. Therefore, in addition to wide swaths, cutting heights ≥6 cm, and angled knives, the use of a hay merger or sidebar rake should be added to the list of best management practices to reduced ash content in alfalfa hay.

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