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Abstract

Horizontal silo piles without walls are constructed using packing equipment to adequately pack the forage for air exclusion. During packing, the equipment uses a ramp of forage to access the top of the pile, potentially introducing soil into the forage when the base of the silo is made of soil. Soil contains microorganisms which may cause malfermentation and pose health risks to livestock. The objective of this study was to assess the association of horizontal silo pad type, elevation, and core depth with indicators related to silage hygiene and nutrient quality. We hypothesized that ash and mineral content, microbiological profile, and fermentation profile in silos with soil pads would be indicative of soil contamination, and that measures of potential contamination would be lesser at higher elevations within the silo. Eleven horizontal silos on 7 farms were sampled in a split-split-plot design, with silo pad type as the whole plot factor, elevation on the ramp as the split-plot factor, and core depth as the split-split-plot factor; data were analyzed using mixed models to appropriately recognize experimental units for each factor. Regardless of core depth and elevation, silage pH was increased in concrete pads relative to soil pads. Also, for soil pads, phosphorus (P) was increased in samples of the outer core depth compared to inner core depths. Further, on both pad types, iron (Fe) content was greater at lower vs. medium elevations, but there was no evidence of difference for peak Fe content compared with the other elevations. On soil pads, outer layers had decreased 120- and 240-hour neutral detergent fiber (NDF) and 7-hour starch digestibility compared with inner cores regardless of elevation. The outer segments also had increased pH and decreased density compared with inner core depths, regardless of pad type or elevation. Further, independent of pad type or elevation, outer layers increased NDF, acid detergent fiber (ADF), lignin, ash, and minerals, but decreased crude protein (CP) compared with inner core depths. Additionally, compared with inner layers, outer layers had decreased NDF and starch digestibility, and increased undigestible NDF regardless of pad type or elevation. Overall, changes in Fe and P may be indicative of soil contamination on soil pads. Furthermore, the decreased quality of forage in the outer layers of the silo reinforces the importance of an anaerobic environment for the adequate preservation of silage.

Keywords

silage hygiene, silage contamination, silage degradation

Association of Horizontal Silo Pad Type, Elevation and Core Depth With Indicators of Silo Ramp Hygiene, Forage Quality, and Digestibility

W.E. Brown, N.M. Bello,[1] and M.J. Brouk

Summary

Horizontal silo piles without walls are constructed using packing equipment to adequately pack the forage for air exclusion. During packing, the equipment uses a ramp of forage to access the top of the pile, potentially introducing soil into the forage when the base of the silo is made of soil. Soil contains microorganisms which may cause malfermentation and pose health risks to livestock. The objective of this study was to assess the association of horizontal silo pad type, elevation, and core depth with indicators related to silage hygiene and nutrient quality. We hypothesized that ash and mineral content, microbiological profile, and fermentation profile in silos with soil pads would be indicative of soil contamination, and that measures of potential contamination would be lesser at higher elevations within the silo. Eleven horizontal silos on 7 farms were sampled in a split-split-plot design, with silo pad type as the whole plot factor, elevation on the ramp as the split-plot factor, and core depth as the split-split-plot factor; data were analyzed using mixed models to appropriately recognize experimental units for each factor. Regardless of core depth and elevation, silage pH was increased in concrete pads relative to soil pads. Also, for soil pads, phosphorus (P) was increased in samples of the outer core depth compared to inner core depths. Further, on both pad types, iron (Fe) content was greater at lower vs. medium elevations, but there was no evidence of difference for peak Fe content compared with the other elevations. On soil pads, outer layers had decreased 120- and 240-hour neutral detergent fiber (NDF) and 7-hour starch digestibility compared with inner cores regardless of elevation. The outer segments also had increased pH and decreased density compared with inner core depths, regardless of pad type or elevation. Further, independent of pad type or elevation, outer layers increased NDF, acid detergent fiber (ADF), lignin, ash, and minerals, but decreased crude protein (CP) compared with inner core depths. Additionally, compared with inner layers, outer layers had decreased NDF and starch digestibility, and increased undigestible NDF regardless of pad type or elevation. Overall, changes in Fe and P may be indicative of soil contamination on soil pads. Furthermore, the decreased quality of forage in the outer layers of the silo reinforces the importance of an anaerobic environment for the adequate preservation of silage.

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Introduction

Achieving high-quality silage on beef and dairy operations requires careful attention to oxygen exclusion to accomplish excellent fermentation. Silage that is inadequately fermented or allowed to spoil during feed-out can develop secondary aerobic fermentation, which increases dry matter loss, reduces dry matter intake and performance by livestock, and may contribute to animal health issues. Specifically, a lack of pH reduction by lactic acid bacteria at the onset of fermentation or in spoiled sections may allow the growth of *Clostridium spp.*, known to have deleterious effects.

Clostridia are ubiquitous, being found in soil, forage, manure, feed, and milk. The microorganisms multiply when they form spores during less-than-ideal growing conditions that re-emerge when the conditions improve. Some evidence suggests that the prevalence of clostridia in silage may be influenced by the application of animal manure and the timing of its application. While some authors have eluded that soil contamination may be the primary cause of *Clostridium spp*. contamination in silage due to their ubiquitous nature in soil, a paucity of work has been conducted to quantify contamination of soil in silage. One group monitored radiocaesium and titanium in fresh forages, soil, and silage over time, presenting evidence that soil contamination did occur between harvest and ensiling. One case study identified an extreme case of sand contamination in a silage pile stored on soil as a causative factor for bovine mortality from rumen sand impaction, thus highlighting the possibility of soil contamination during packing by inexperienced individuals. Content of ash and Fe has been utilized as a measure of soil contamination of silages after flooding events, and for hay during normal harvest conditions utilizing different harvesting methods.

Approximately 90% of U.S. dairy farms feed corn silage, and many large farms utilize drive-over silage piles of some type to store large quantities of forage. Drive-over silage piles may have a base of soil, or a harder base such as concrete or asphalt. Therefore, considering the ubiquitous nature of clostridia bacteria in soil, the objective of this study was to assess the association between silage pad type, elevation, and core depth with silage hygiene and nutritional characteristics. We hypothesized that ash and mineral content would be greater on silage piles stored on soil compared with concrete, and that those piles would have greater counts of clostridial bacteria. We also hypothesized that the ash and mineral content would be greater at lower elevations where tires first interact with the ramp.

Experimental Procedures

This observational trial was conducted from November 2019 to March 2020 on 7 farms in north central and western Kansas using forages grown in 2019. All silages had fermented for at least 60 days. In total, 11 drive-over corn, sorghum, and triticale silage piles were sampled, 3 of which were on concrete pads with the remainder on soil pads. Detailed explanation of the silage piles sampled are provided in Table 1. All silage piles were covered with plastic.

Each pile was sampled at 18 locations on the silo ramp where tractors accessed the pile for packing, with cores obtained at an elevation of approximately 2 ft (LOW), 4 ft (MED), and at the peak (PEAK; approximately 18 ft). Specifically, 6 cores were obtained across the ramp at each elevation. Cores of 18 to 22 inches in length were obtained with a coring device 2 inches in width. Cores were separated into two segments, 1) 6 inches of the core representing the outer layers of the silage pile, and 2) the remainder of the core (6 to 22 inches) representing the inner portions of the pile.

After samples were collected, three samples (core triad) from the same median plane, elevation, and core depth were composited for a total of 6 samples for each ramp at each core depth. One half of the silage composite was evaluated for chemical composition by near-infrared spectroscopy (Rock River Laboratory, Inc., Watertown, WI). The remaining half of the composite sample was sent overnight to ARM & HAMMER Animal Nutrition (Waukesha, WI) for microbial analysis and fermentation acid profile.

The study was conducted using a split-split-plot design in a randomized block design with subsampling, with farm as an overarching blocking structure, silo pad type as the whole plot factor, silo as the whole plot, elevation as the split-plot factor, and core depth as the split-split-plot factor. A general linear mixed model was utilized for analysis of continuous variables using the GLIMMIX procedure in SAS (version 9.4, SAS Institute, Cary, NC). Fixed effects included pad type, core depth, elevation, their 2- and 3-way interactions, and forage type. Random effects included farm, silage pile (identified as the cross-product of farm by pad type), main core triad (identified by the cross-product of farm by pad type by elevation), and core triad nested within a pair of elevation-specific triads (identified by the cross-product of farm by pad type by elevation by core depth), in order to properly recognize the size of the experimental unit for each factor. Responses were either transformed for variance stabilization, or heterogeneous variances were explicitly specified, as appropriate in each case. Model assumptions were evaluated using externally studentized residuals and were considered to be appropriately met. Outliers were diagnosed using an extremely conservative Bonferroni test on studentized residuals.

Results and Discussion

Contrary to our hypothesis, there was no evidence for any differences between pad types in ash, Fe, or *Clostridia spp*. We noted interactions involving pad type for P whereby samples had increased P for outer vs. inner core depths in piles stored on soil, but there was no evidence of difference between core depths on concrete pads. However, we consider these results inconclusive since differences were not noted for other minerals. For soil pads, P was greater in outer vs. inner core depths ($P = 0.03$; Table 7), but there was no evidence of difference between core depths for concrete pads. This could indicate some soil contamination for soil pads, though these results were not consistent with our findings for ash. Coincidentally, the 120-hour ($P = 0.02$) and 240-hour NDF ($P = 0.04$), and 7-hour starch ($P < 0.001$) digestibility were both reduced in outer layers for soil pads compared with concrete pads (Table 7). A direct mechanism for why this occurred on soil pads but not concrete pads is elusive based upon our data, especially considering the lesser pH of soil pads.

The lack of evidence for differences between pad types on ash and minerals may reflect the care taken by drivers of packing equipment not to incorporate soil into the pile, or variability of deterioration in the outer layers of the silage. The degradation in the outer layer of the silage concentrated the ash component, and variability in degradation between silos may have been greater than any introduction of ash from the soil making it difficult to detect differences. The ability to detect significant differences in ash in the outer layer of these piles may have been easier in fresh silage that had not yet been covered.

Most of the significant effects identified in this experiment were for core depth. In our study, lactic acid was greater ($P < 0.001$) and pH was lesser ($P = 0.01$) in inner vs. outer core depths. The outer layers of the silage are more exposed to oxygen, which promotes aerobic degradation, leading to the decreased lactic acid concentration that we observed, and the concomitant increase in pH in outer layers. Butyric acid was only detectable in 7 of the 124 samples analyzed, which is indicative of high-quality fermentation and lack of clostridial fermentation in the silage pile ($P > 0.35$). Of the 7 samples in which butyric acid was detected, 6 were in the outer core depths.

As expected, the aerobic degradation in the outer layers lead to a reduction in the nutritive quality of the forage (Table 2). Indeed, there was an increase in NDF organic matter (NDFom) ($P = 0.08$), ADF ($P = 0.05$), lignin ($P < 0.001$), and a decrease in CP ($P = 0.01$) in outer cores vs. inner cores. The digestibility of the fiber ($P < 0.01$) and 0-hour starch ($P = 0.01$) also decreased in the outer layers compared with inner layers, resulting in greater undigestible NDF ($P \leq 0.01$) and a marginally significant lesser total tract NDF digestibility ($P = 0.06$). Feeding deteriorated silage to livestock *in vivo* has a marked ability to decrease apparent digestibility. Overall, the degradation of carbohydrate and protein leads to a loss of dry matter and an increase in inorganic substances remaining as ash. Our data demonstrate an increase in ash in the outer layers where degradation was present compared with inner layers, and the minerals potassium, P, magnesium, and Fe increased in those outer vs. inner depths, regardless of pad type or elevation along the silage ramp.

In this study, only yeast and clostridia were detectable in sufficient samples to warrant analysis. There was no evidence of any differences between pad type, core depth, or elevation in the probability of finding yeast (Table 5) nor for the quantification of *Clostridia spp.* (Table 4). However, of those samples on which yeast were detected, greater concentrations of yeast were found in the outer layer relative to the inner layer, though only at medium elevations of the silage ramp (Table 9). An increase in yeasts and molds in the outer layers of the silage pile is common, but differences in enumeration of *Clostridia spp.* is generally mixed.

Conclusions

There were minor indications that soil contamination may have occurred based on the increased mineral content of Fe at low elevations, and for P in outer layers in soil pads. Further, soil pads reduced 120- and 240-hour NDF and 7-hour starch digestibility for outer layers. The most numerous effects noted in this study were for core depth, where outer layers exhibited decreased density, nutritive quality, and nutrient digestibility. Future work should incorporate a more balanced experimental design to increase statistical power and should evaluate single forage types with high buffering capacity that may be more prone to malfermentation from soil bacterial contamination, such as alfalfa or winter forage crops. Further, efforts to secure samples prior to fermentation and degradation of outer layers may enhance the ability to detect subtle differences in ash and mineral content as indicators of soil contamination.

Table 1. Description of horizontal silo forage type and pad type by farm

Item	Pad type	Forage
Farm 1		
Silo 1	Soil	Corn
Silo 2	Soil	Corn
Farm 2		
Silo 1	Soil	Sorghum
Farm 3		
Silo 1	Soil	Triticale
Silo 2	Concrete	Sorghum
Farm 4		
Silo 1	Concrete	Sorghum
Farm 5		
Silo 1	Soil	Triticale
Silo 2	Concrete	Corn
Farm 6		
Silo 1	Soil	Corn/Sorghum
Farm 7		
Silo 1	Soil	Corn
Silo 2	Soil	Corn

Table 2. Association of pad type, elevation, and core depth with the chemical composition (as determined by NIR) and density of silage samples obtained from horizontal silo ramps

	Pad[1]		Elevation[1]			Core depth[1]		*P*-value[2]					
Item[1]	Conc	Soil	Low	Med	Peak	Inner	Outer	Pad	Elev	Core	Pad × elev	Pad × core	Elev × core
DM, %	38.1	34.5	36.4	36.5	36.0	36.0	36.6	0.55	0.89	0.55	0.99	0.28	0.63
	±0.13	±0.07	±0.08	±0.08	±0.08	±0.07	±0.07						
pH	5.0	4.8	4.8	4.8	4.9	4.8	4.9	0.02	0.45	0.01	0.74	0.45	0.43
	±0.10	±0.10	±0.10	±0.10	±0.10	±0.10	±0.10						
CP, %	9.6	10.4	10.0	9.9	10.1	9.9	10.1	0.16	0.56	0.01	0.27	0.21	0.11
	±0.41	±0.29	±0.31	±0.31	±0.31	±0.30	±0.30						
aNDF, %	47.5	46.4	46.8	46.9	47.1	46.5	47.4	0.62	0.92	0.08	0.95	0.88	0.90
	±1.64	±0.94	±1.00	±1.00	±1.00	±0.98	±0.97						
aNDFom, %	43.8	43.0	43.3	43.5	43.5	43.0	43.8	0.91	0.92	0.12	0.98	0.47	0.86
	±5.03	±3.56	±3.10	±3.10	±3.10	±3.09	±3.09						
ADF, %	33.3	32.5	32.9	32.8	33.0	32.5	33.3	0.56	0.88	0.05	0.45	0.78	0.99
	±1.14	±0.64	±0.71	±0.71	±0.71	±0.68	±0.68						
Lignin, %[4]	5.2	5.2	5.2	5.1	5.3	5.0	5.4	0.87	0.76	<0.001	0.24	0.37	0.39
	[4.3, 6.3]	[4.7, 5.9]	[4.8, 5.7]	[4.7, 5.6]	[4.9, 5.7]	[4.7, 5.4]	[5.1, 5.8]						
Starch, %	13.3	13.8	13.3	13.6	13.6	13.6	13.5	0.86	0.91	0.92	0.77	0.78	0.71
	±2.03	±1.14	±1.23	±1.23	±1.23	±1.19	±1.19						
Ash, %	12.6	10.7	11.8	11.1	11.9	10.9	12.3	0.48	0.12	<0.001	0.23	0.35	0.33
	±0.17	±0.10	±0.10	±0.10	±0.11	±0.10	±0.10						
K, %	2.4	2.1	2.3	2.2	2.3	2.2	2.3	0.45	0.64	0.001	0.51	0.41	0.56
	±0.23	±0.14	±0.14	±0.14	±0.14	±0.14	±0.14						
P, %[5,6]	-	-	-	-	-	-	-	0.42	0.14	0.04	0.01	0.03	0.13

continued

Table 2. Association of pad type, elevation, and core depth with the chemical composition (as determined by NIR) and density of silage samples obtained from horizontal silo ramps

	Pad[1]		Elevation[1]			Core depth[1]		*P*-value[2]					
Item[1]	Conc	Soil	Low	Med	Peak	Inner	Outer	Pad	Elev	Core	Pad × elev	Pad × core	Elev × core
Ca, %[4]	0.45 [0.27, 0.77]	0.32 [0.24, 0.44]	0.40 [0.32, 0.49]	0.37 [0.30, 0.46]	0.38 [0.31, 0.47]	0.37 [0.33, 0.49]	0.40 [0.32, 0.49]	0.15	0.27	0.01	0.77	0.36	0.85
Mg, %	0.27 ±0.03	0.27 ±0.02	0.27 ±0.02	0.27 ±0.02	0.27 ±0.02	0.26 ±0.02	0.28 ±0.02	0.98	0.54	<0.001	0.98	0.48	0.55
Fe, ppm[4]	418 [151, 1156]	468 [262, 835]	518[a] [347, 774]	381[b] [255, 569]	438[ab] [293, 656]	394 [271, 573]	496 [341, 722]	0.78	0.02	0.01	0.29	0.37	0.23
NH_3 N, %	0.17 ±0.01	0.17 ±0.007	0.18 ±0.008	0.18 ±0.008	0.17 ±0.008	0.17 ±0.008	0.18 ±0.008	0.69	0.42	0.06	0.65	0.71	0.17
NH_3 N, % CP[4]	10.2 [7.8, 13.0]	8.9 [7.6, 10.3]	9.6 [8.5, 10.8]	9.9 [8.8, 11.1]	9.3 [7.8, 10.7]	9.5 [8.5, 10.7]	9.6 [8.5, 10.8]	0.23	0.61	0.93	0.94	0.33	0.28
ADICP, %	0.85 ±0.097	0.91 ±0.056	0.90 ±0.061	0.87 ±0.061	0.88 ±0.061	0.86 ±0.059	0.90 ±0.059	0.64	0.88	0.19	0.58	0.86	0.99
ADICP, % CP	8.5 ±1.07	8.7 ±0.62	8.8 ±0.64	8.5 ±0.64	8.5 ±0.64	8.2 ±0.63	9.0 ±0.63	0.85	0.40	<0.01	0.70	0.48	0.88
Lactic acid, %	2.03 ±0.86	3.37 ±0.50	2.73 ±0.54	2.79 ±0.54	2.57 ±0.55	3.34 ±0.51	2.05 ±0.53	0.40	0.81	<0.001	0.75	0.50	0.86
Acetic acid, %[5]	-	-	1.80 ±0.37	1.75 ±0.37	1.63 ±0.38	-	-	0.49	0.68	0.30	0.82	0.07	0.82
Density, kg DM/m[3,4,7]	243 [164, 359]	272 [217, 240]	-	-	-	-	-	0.48	0.74	0.05	0.90	0.11	0.08

[1]Means are reported with ± SEM unless denoted otherwise.
[2]There was no evidence for any 3-way interaction ($P > 0.27$).
[3]Percentage values are represented as % of dry matter (DM) unless otherwise noted.
[4]Means are reported with 95% confidence interval due to transformation of the data.
[5]Estimated means for the group effects by combination of pad type and core depth are reported in Table 7.
[6]Estimated means for the group effects by combination of pad type and elevation are reported in Table 8.
[7]Estimated means for the group effects of elevation and core depth are reported in Table 9.
[a,b]Estimated marginal means for elevation with differing superscripts are different ($P < 0.05$).
NIR = near-infrared spectroscopy. CP = crude protein. aNDF = adjusted neutral detergent fiber. aNDFom = Amylase-treated neutral detergent fiber as a % of organic matter. ADF = acid detergent fiber. K = potassium. P = phosphorus. Ca = calcium. Mg = magnesium. Fe = iron. N = nitrogen. ADICP = acid detergent insoluble crude protein.

Table 3. Association of pad type, elevation, and core depth with the digestibility (as determined by near infrared spectroscopy (NIR)) of silage samples obtained from horizontal silo ramps

	Pad[1]		Elevation[1]			Core depth[1]		*P*-value[2,3,4]			
Item	Conc	Soil	Low	Med	Peak	Inner	Outer	Pad	Elev	Core	Pad × core
NDF digestibility											
30 h, % NDF[5]	41.8	44.3	43.3	43.3	42.5	44.3	41.7	0.31	0.55	0.001	0.27
	[35.6, 47.1]	[41.1, 47.3]	[40.7, 45.8]	[41.0, 45.5]	[40.1, 44.8]	[42.2, 46.3]	[39.5, 43.9]				
48 h, % NDF[5]	56.6	57.8	57.4	57.9	56.3	58.2	56.2	0.74	0.36	<0.01	0.38
	[46.3, 65.3]	[52.2, 63.0]	[53.4, 61.1]	[54.0, 61.5]	[52.4, 60.1]	[54.7, 61.6]	[52.5, 59.6]				
120 h, % NDF[5,6]	-	-	60.1	60.9	59.1	-	-	0.79	0.35	<0.01	0.02
			[56.0, 64.0]	[56.8, 64.7]	[55.0, 63.0]						
240 h, % NDF[5,6]	-	-	61.8	63.2	60.9	-	-	0.90	0.19	<0.01	0.04
			[57.1, 66.2]	[58.6, 67.5]	[56.1, 65.3]						
Undigestible NDF											
30 h, % DM	27.6	25.7	26.5	26.4	27.1	25.8	27.6	0.12	0.43	<0.001	0.40
	[25.2, 30.3]	[24.3, 27.3]	[25.3, 27.8]	[25.3, 27.6]	[25.9, 28.3]	[24.8, 26.8]	[26.6, 28.7]				
120 h, % DM	20.5	20.2	20.3	20.0	20.9	19.8	20.9	0.90	0.25	0.01	0.19
	±1.71	±1.04	±1.09	±1.09	±1.09	±1.07	±1.07				
240 h, % DM	19.3	19.1	19.1	18.8	19.7	18.6	19.8	0.94	0.21	0.01	0.28
	±1.72	±1.05	±1.09	±1.09	±1.09	±1.07	±1.07				
TTNDFD, % NDF[7]	36.1	34.4	35.5	35.8	34.4	35.8	34.7	0.60	0.46	0.06	0.86
	±2.43	±1.44	±1.57	±1.57	±1.56	±1.43	±1.44				
Starch digestibility											
0 h, %	32.5	27.8	29.6	29.1	31.9	32.4	28.0	0.35	0.46	0.01	0.81
	±2.52	±1.48	±2.05	±2.04	±2.01	±1.66	±1.73				
7 h, %[6]	-	-	65.3	65.8	67.9	-	-	0.67	0.18	0.19	<0.001
			±1.86	±1.88	±1.86						

continued

Table 3. Association of pad type, elevation, and core depth with the digestibility (as determined by near infrared spectroscopy (NIR)) of silage samples obtained from horizontal silo ramps

	Pad[1]		Elevation[1]			Core depth[1]		*P*-value[2,3,4]			
Item	Conc	Soil	Low	Med	Peak	Inner	Outer	Pad	Elev	Core	Pad × core
Milk2006 30 hr											
kg milk/mt	1,070	1,085	1,072	1,099	1,061	1,110	1,045	0.74	0.16	<0.001	0.89
	±69.7	±47.0	±33.4	±33.4	±33.4	±30.8	±30.8				
TDN, %	48.2	52.6	50.2	50.9	50.0	51.2	49.6	0.08	0.20	<0.001	0.88
	±1.56	±1.00	±1.04	±1.04	±1.04	±1.02	±1.02				
NE_L, Mcal/kg	1.21	1.20	1.20	1.23	1.20	1.23	1.18	0.75	0.12	<0.001	0.34
	±0.014	±0.009	±0.010	±0.010	±0.010	±0.010	±0.010				
Milk2006 48 hr											
kg milk/mt	1,182	1,151	1,156	1,186	1,157	1,192	1,140	0.68	0.16	<0.001	0.71
	±88.2	±49.5	±49.7	±49.7	±49.7	±49.6	±49.6				
TDN, %	50.4	54.1	52.0	52.8	51.9	52.9	51.6	0.11	0.19	<0.001	0.81
	±1.50	±1.00	±1.01	±1.01	±1.01	±1.00	±1.00				
NE_L, Mcal/kg	1.23	1.22	1.22	1.24	1.21	1.25	1.20	0.68	0.09	<0.001	0.31
	±0.016	±0.010	±0.011	±0.011	±0.011	±0.010	±0.010				

[1]Estimated means are reported with ± SEM unless otherwise noted.
[2]There was no evidence for any 3-way interaction ($P > 0.17$).
[3]There was no evidence for any 2-way interaction between pad type and elevation ($P > 0.13$).
[4]There was no evidence for any 2-way interaction between elevation and core depth ($P > 0.14$).
[5]Estimated means are reported with the 95% confidence interval after back-transformation of the data.
[6]Estimated means for the group effects of pad type and core depth are reported in Table 7.
[7]Total tract neutral detergent fiber (NDF) digestibility.
NIR = near-infrared spectroscopy. DM = dry matter. TDN = total digestible nutrients. NE = net energy.

Table 4. Association of pad type, elevation (elev), and core depth with the quantification of *Clostridium spp.* and yeast from silage samples obtained on horizontal silo ramps

	Pad[1]		Elevation[1]			Core depth[1]		*P*-value[2]					
Item	Concrete	Soil	Low	Medium	Peak	Inner	Outer	Pad	Elev.	Core	Pad × elev	Pad × core	Elev × core
log_{10} CFU/g[3]													
Clostridia	2.4 ±0.59	2.5 ±0.37	2.5 ±0.31	2.3 ±0.32	2.7 ±0.32	2.4 ±0.30	2.6 ±0.31	0.92	0.23	0.12	0.10	0.11	0.87
Yeast[4]	5.3 ±0.80	5.0 ±0.46	-	-	-	-	-	0.72	0.47	<0.01	0.40	0.64	0.05

[1]Estimated means are reported with ± SEM.
[2]There was no evidence for any 3-way interaction ($P > 0.38$).
[3]Data for quantification of CFU was determined only using data for samples greater than the minimum detectable limit as outlined in Table 5.
[4]Estimated means for the group effects of elevation and core depth are reported in Table 9.

Table 5. Association of pad type, elevation, and core depth on the probability of detection of *Clostridium spp.* and yeast in silage samples obtained from horizontal silo ramps

	Microbe type
Item	Yeast probability (95% CI)
Pad type	
Concrete	0.95 (0.06, 1.00)
Soil	0.76 (0.16, 0.98)
Elevation	
Low	0.91 (0.44, 0.99)
Medium	0.89 (0.38, 0.99)
High	0.86 (0.34, 0.99)
Core depth	
Inner	0.87 (0.43, 0.98)
Outer	0.90 (0.49, 0.99)
P-value	
Pad	0.42
Elevation	0.87
Core depth	0.69
Pad × elevation	0.54
Pad × core	0.69
Elevation × core	0.46
Pad × elevation × core	0.53

Table 6. Empirical prevalence of microbiological species silage samples obtained from the ramp of horizontal silos

Item	Total detected, n[1]
Clostridia spp.	89/124 (0.71)
C. perfringens	44/124 (0.35)
E. coli	29/124 (0.23)
Total coliforms	54/124 (0.45)
Yeast	84/124 (0.68)
Mold	46/124 (0.37)

[1]Proportion of samples in which a given microbe type was detected, and percent of total in the parenthesis.

Table 7. Estimated group-level means for outcomes with marginally or significant interactions between pad type and core depth

	Concrete[1]		Soil[1]		*P*-value
Item	Inner	Outer	Inner	Outer	Pad × core
Phosphorus, %[2]	0.24	0.24	0.25[a]	0.27[b]	0.03
	[0.22, 0.27]	[0.22, 0.27]	[0.23, 0.27]	[0.25, 0.29]	
Acetic acid, %	1.68	1.23	1.94	2.07	0.07
	±0.63	±0.63	±0.36	±0.37	
NDFd 120 h, % NDF[2]	59.8	59.2	62.4[a]	58.7[b]	0.02
	[53.2, 65.7]	[52.6, 65.2]	[58.7, 65.9]	[54.6, 62.4]	
NDFd 240 h, % NDF[2]	62.1	61.3	64.5[a]	59.9[b]	0.04
	[51.7, 71.0]	[50.8, 70.2]	[59.1, 69.6]	[54.0, 65.2]	
Starch digestibles, 7 h, %	64.8	66.6	68.9[a]	64.8[b]	<0.001
	±2.49	±2.49	±1.76	±1.78	

[1]Estimated means are reported with ± SEM unless otherwise noted.
[2]Estimated means are reported with 95% confidence intervals after back-transformation of the data.
[a,b](Adjusted $P < 0.05$) Differences between elevations within a given pad type, either concrete or soil.
NDF = neutral detergent fiber.

Table 8. Estimated group-level means for outcomes with significant interactions between pad type and elevation

	Concrete			Soil			Pad ×
Item	Low	Medium	Peak	Low	Medium	Peak	elevation
Phosphorus, %[1]	0.23[a]	0.24[ab]	0.26[b]	0.26	0.26	0.26	0.01
	[0.20, 0.26]	[0.21, 0.27]	[0.23, 0.30]	[0.24, 0.29]	[0.24, 0.28]	[0.23, 0.28]	

[1]Estimated means are reported with the 95% confidence interval after back-transformation of the data.
[a,b](Adjusted $P < 0.05$) Differences between elevations within a given pad type, either concrete or soil.

Table 9. Estimated group-level means for variables with a marginal or significant interaction between elevation and core depth

	Low		Med		Peak		*P*-value
Item	Inner	Outer	Inner	Outer	Inner	Outer	Elevation × core
Density, kg/m[3, 1]	276	249	279[a]	235[b]	247	258	0.08
	[234, 326]	[210, 293]	[236, 329]	[199, 277]	[209, 291]	[218, 304]	
Yeast, $\log_{10}$ CFU/g[2]	5.2	5.2	4.1[a]	5.5[b]	5.1	5.8	0.05
	±0.58	±0.56	±0.58	±0.57	±0.56	±0.58	

[1]Estimated means are presented with the 95% confidence intervals after back-transformation.
[2]Estimated means are presented with ± SEM.
[a,b](Adjusted $P < 0.05$) Differences between core depths within a given elevation, either low, medium, or peak.