Rain Damage and Spontaneous Heating in Southern Forages Harvested as Hay

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Introduction

One of the most common problems faced by hay producers is how to manage hay production schedules around unfavorable weather. This problem is particularly frustrating throughout the spring and early summer when the probability of rainfall events is high. Inevitability, some wilting forage crops are damaged by unexpected rainfall events each year, and producers often inquire about the effects of unexpected rain damage, and what impact this may have on subsequent animal performance. In truth, the scope of the problem is considerably more complex than direct damage to wilting forage crops via leaching, reactivated respiratory processes, and/or leaf shatter. Common consequences of uncooperative weather also may include: i) spontaneous heating and/or combustion that occurs when producers try to complete baling operations of incompletely wilted forage prior to an oncoming rainfall event; ii) a combination of rain damage and spontaneous heating that may occur with multiple rainfall events or prolonged unstable weather; and iii) excessively mature forage that results from delaying haymaking operations until weather is more favorable. Producers are often unaware or unconcerned about the last consequence, but maturity effects on forage quality can be every bit as severe as spontaneous heating and/or rain damage.

Effects of Maturity on Forage Quality

Generally, the effects of maturity on forage quality are well known to most producers; more than any other factor, the maturity level of the forage at the time of harvest determines the quality of the hay. Generally, the ratio of leaf and stem tissues declines as forages mature. This results in greater concentrations of fiber components, such as NDF, ADF, and lignin, but lower concentrations of CP, digestible dry matter, and energy. Figure 1 illustrates the effect of growth stage on the concentration of NDF for tall fescue forage (Ball et al., 2002). Between the late-boot and soft dough stages of growth, NDF increased by about 12 percentage units from 53 to 65%. A similar response can be expected for other southern forages, such as bermudagrass (Table 1). This is important for several reasons. First, as concentrations of NDF increase, the digestibility (Figure 1) of these same forages decreases concomitantly. Secondly, higher concentrations of NDF are frequently associated with poorer voluntary intakes by livestock consuming forage-based diets. This is especially important when the livestock class consuming the forage has high nutrient demands, such as those of dairy or stocker cattle. Finally, and most importantly, these concepts are important because they illustrate that there is always a cost associated with delaying harvest because of potential rainfall events, and these costs result in a forage of lower nutritional value that will not be consumed as readily by livestock.

Effects of Rainfall on Dry Matter Loss and Forage Quality

Overview. Rainfall applied to wilting forages will leach soluble nutrients (primarily sugars) from hay, resulting in DM loss, increased concentrations of fiber components, and decreased energy density within the forage. Leaching losses are a function of the forage species, the DM content of the forage at the time the rainfall event occurs, the sugar content of the forage, and the number, amount, intensity, and/or duration of the rainfall event or events. Plant sugars are assumed to be 100% digestible; therefore, leaching causes the loss of the most digestible components of the forage. Rain also can reactivate respiration by plant enzyme systems and other microorganisms associated with the forage plants (Rotz and Muck, 1994). This causes additional plant sugars to be consumed, resulting in additional DM loss and further reductions in the nutritional value of the forage. Significant losses of DM also can occur directly as a result of leaf shatter, especially if the hay crop is a legume. In addition, any rainfall during the wilting process may lead to additional tedding and raking operations that result in even more leaf shatter before the forage is dry enough to bale. However, since the production of legume hays is less common in the southeastern US than in many other parts of the country, the concepts of leaf shatter and rain damage to wilting legume forages will not be discussed further.

Losses of DM from Wilting Orchardgrass Forages. Recently, studies conducted at the University of Arkansas evaluated losses of DM and changes in nutritive value for wilting orchardgrass and bermudagrass forages (Scarbrough et al., 2005) damaged by rainfall delivered from a rainfall simulator. From 0 to 76 mm (0 to 3 inches) of simulated rainfall were applied to both forages in single rainfall events in 12.5-mm (0.5-inch) increments. Rainfall was applied to orchardgrass when the moisture content of the forage was very high (67.4%), ideal for baling (15.3%), and excessively dry (4.1%).

Losses of DM for the orchardgrass were low (< 2%) if rainfall occurred when the forage moisture content was high (67.4%), but increased substantially if rainfall occurred when the forage was dry (Table 2). Losses of 10.7% of total plant DM occurred when 76 mm of rainfall were applied to excessively dry (4.1%) forage. At an ideal moisture for baling (15.3%), maximum losses were only slightly lower, reaching 8.8% of DM. Regardless of the moisture content of the forage, DM losses for dry forages increased with the amount of rainfall in curvilinear patterns, but losses were disproportionally large at rainfall increments of 13, 25, and 38 mm, and tended to level off as cumulative rainfall increased beyond these levels.

For bermudagrass (Table 3), rainfall treatments were applied immediately after mowing (76.1%), at the approximate midpoint of the wilting period (40%), and when the forage moisture content was ideal for baling (13.0%). There was essentially no DM loss when the forage was wet, but drier forages lost measurable DM with increased rainfall. Greater losses of DM occur in drier forages because plant cells lose their integrity, and can no longer regulate the movement of soluble compounds in or out of the cell. Unlike orchardgrass, maximum DM losses for bermudagrass were quite limited; the forage that was ideal for baling (13.0%) lost a maximum of 2.1% of total plant DM. Perhaps these differences can be explained on the basis of the sugar content of each grass. Perennial cool-season grasses, such as orchardgrass, have much higher concentrations of water-soluble plant sugars and other compounds than bermudagrass or other warm-season perennial grasses. Therefore, orchardgrass has the potential for more DM loss through leaching. Figure 3 illustrates the comparison of DM losses for bermudagrass and orchardgrass when both forages were wilted to an ideal moisture content for baling; DM losses for orchardgrass were at least four times greater than observed for bermudagrass after the rainfall amount reached 51 mm.

Changes in Nutritive Value for Grasses. The summary of nutritive value for rain-damaged orchardgrass forages (Table 2) demonstrates that relatively wet (67.4%) forage was affected only minimally. Drier forages (4.1 or 15.3% moisture) exhibited more undesirable changes in response to simulated rainfall. Theoretically, fiber components (NDF, ADF, and lignin) are not water soluble; therefore, their concentrations should increase as soluble plant sugars are leached away during the application of simulated rainfall. Generally, our results supported this premise; concentrations of these fiber components increased in curvilinear patterns by as much as 7.8, 9.9, and 3.74 percentage units, respectively,

For bermudagrass (Table 3), changes in nutritive value followed patterns that were similar to those observed for orchardgrass, except that the magnitude of the responses was generally smaller. Maximum increases in NDF, and ADF in response to 76 mm of simulated rainfall were only 2.9 and 2.2 percentage units, respectively, and were observed for forage wilted to 40.0% moisture prior to the rainfall event. For bermudagrass that was dry enough for baling (13.0%), respective increases in NDF and ADF in response to 76 mm of simulated rainfall were only 1.3 and 1.1 percentage units. While the nutritive value of bermudagrass remained relatively stable in response to simulated rainfall, it should not be assumed that rain-damaged forages are as palatable, and they may not be consumed as readily by livestock.

Rainfall Effects on Tall Fescue and Subsequent Intake by Steers

Recently, another series of experiments were completed at the University of Arkansas that assessed the effects of naturally occurring rainfall and subsequent spontaneous heating during storage on the nutritive value of wilting tall fescue forage (Turner et al., 2003), and subsequent effects on voluntary intake and digestibility by growing steers (Turner et al., 2004). Tall fescue was baled at slightly above the recommended moisture content (22.5%), at an ideal moisture for baling (16.4%), and when it was excessively dry (9.9%) without rain damage. In addition, tall fescue was baled at 24.6% moisture after a 23-mm rainfall event, and at 9.3% moisture following three rainfall events totaling 71 mm. The tall fescue was mowed in late-May at the heading stage of growth. At baling, a 23-mm rainfall event increased ($P < 0.01$) the concentration of NDF by 4.9 percentage units compared to all hays baled without rain damage (72.0 vs. 67.1%), while digestibility was suppressed by 1.8 percentage units (63.6 vs. 61.8%). After three rainfall events totaling 71 mm, NDF was further increased ($P < 0.01$) to 76.4%, which was an increase of 8.7 percentage units over hay baled at an ideal 16.4% moisture; however, the associated reduction in digestibility was only 3.2 percentage units. Generally, the effects of a single 23-mm rainfall event were not excessive, especially compared to the rapid changes in nutritive value that may occur as a result of delaying harvest (see Figure 1). However, substantial increases in NDF were observed in hay that was subjected to three rainfall events totaling 71 mm.

After storage, there were few differences in nutritive value between bales that incurred modest spontaneous heating, rain damage, or both (Table 5). This strongly suggests that the practice of baling hay when slightly wet in order to avoid an unexpected shower offers little nutritional (chemical) advantage over waiting to bale until after the rainfall event; however, waiting out the shower will likely require additional raking and tedding operations. Spontaneous heating is highly dependent on the moisture content of the hay. Therefore, producers may have difficulty evaluating what is marginally wet, and the potential for serious depressions in nutritive value as a result of excessive spontaneous heating is quite high.

The voluntary intakes of these fescue hays (Table 6) were identical for hays baled without rain damage, regardless of whether they incurred modest spontaneous heating or not. It is important to note that the levels of spontaneous heating in these hays were very modest because of the relatively low moisture levels (< 25%) at baling, the small rectangular bale packages, and a period of relatively cool weather that occurred within two weeks of baling. More intense heating would be expected if these hays had been packaged as large round bales. Hays that were damaged by rain or rain and modest spontaneous heating were not consumed as well by steers. Depressions ($P = 0.01$) in daily voluntary hay intake, relative to those baled without rain damage, were 0.17% of bodyweight for hay receiving 71 mm of rain prior to baling, and 0.25% of bodyweight for hay receiving a single 23-mm rainfall event coupled with modest spontaneous heating. Therefore, there was about a 10% reduction in voluntary hay intake in any forage damaged by at least one soaking rain. Coefficients of apparent digestibility for DM, OM, and NDF were greater ($P \leq 0.03$) for hays damaged by rainfall events; this may have been related to total tract retention times that were numerically, but not statistically ($P > 0.10$), longer than observed for hays not damaged by rain.

Recommendation

Given the uncertainty of the weather, specific recommendations are difficult. For tall fescue, results of experiments at the University of Arkansas indicate that the damage created by a single rainfall event of approximately 25 mm is not excessive, particularly when compared to the consequences of spontaneous heating, or the rapid negative changes in forage quality that occur when harvest is delayed. This suggests that producers could be more aggressive during the late-spring with fairly limited risk. Orchardgrass and legumes may be more susceptible to rain damage, and may need to be managed more conservatively. In contrast, the quality characteristics of bermudagrass (and likely other perennial warm-season grasses) are only affected minimally by rainfall events; however, this may be less important because weather patterns usually become more stable during summer months. Although there are relatively few studies assessing the impacts of rain damage on voluntary intake of hay by livestock, these studies suggest that a 10% reduction in response to a soaking rain may serve as a good ‘rule of thumb’ until additional studies provide more information.

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Table 1. Fiber characteristics of ‘Coastal’ bermudagrass (adapted from NRC, 1989).

Stage of growth	CP	NDF	ADF	TDN
	% of DM			
early vegetative	16.0	66	30	61
late vegetative	16.5	70	32	54
15 to 28 days	16.0	74	33	55
29 to 42 days	12.0	76	38	50
43 to 56 days	8.0	78	43	43

Table 2. Effects of crop moisture content and amount of rainfall on the nutritive value of wilting orchardgrass hay. Orchardgrass forage was harvested on 18 June 2001, which was the second harvest of the growing season. Simulated rainfall was applied at a rate of 76 mm/h (adapted from Scarbrough et al., 2005).

Moisture[a]	Amount	DM loss	CP	NDF	ADF	Lignin
%	mm	------------------------------	------------------------------	% of DM	------------------------------	------------------------------
67.4	0	0	13.2	63.6	35.5	3.36
	13	0.6	13.4	64.0	36.5	3.04
	25	1.2	14.2	64.4	37.0	3.24
	38	1.2	14.3	64.4	37.5	3.87
	51	1.9	13.9	64.9	36.6	4.03
	64	1.6	13.9	64.7	35.0	2.70
	76	1.4	15.2	64.5	34.2	2.71
	Effect[b]	L < 0.01	L < 0.01	L < 0.01	Qu = 0.04	Qu < 0.01
15.3	0	0	13.6	65.0	34.7	2.85
	13	5.7	14.9	68.9	37.4	4.31
	25	5.0	14.5	68.4	39.3	4.62
	38	7.3	14.5	70.1	39.9	4.55
	51	8.3	15.0	70.9	40.3	5.39
	64	8.6	13.9	71.2	42.1	5.43
	76	8.8	14.4	71.3	44.6	6.59
	Effect	Qu = 0.01	Q = 0.04	Qu = 0.02	C < 0.01	C < 0.01
4.1	0	0	13.8	65.2	34.0	3.91
	13	5.8	13.6	69.3	35.3	6.20
	25	7.6	13.4	70.6	36.5	4.87
	38	8.4	14.4	71.2	36.5	5.91
	51	9.1	14.1	71.7	37.5	4.09
	64	10.1	13.9	72.6	37.8	3.87
	76	10.7	14.3	73.0	38.3	4.28
	Effect	L = 0.03	NS	C = 0.05	L < 0.01	C = 0.04

[a] Moisture content of the forage when the simulated rainfall was applied.
[b] Highest order effect of rainfall amount: NS, nonsignificant (P > 0.05); L, linear; Q, quadratic; C, cubic; and Qu, quartic.

Table 3. Effects of crop moisture content and amount of rainfall on the nutritive value of wilting bermudagrass hay. Bermudagrass was harvested on 30 August 2001. Simulated rainfall was applied at a rate of 76 mm/h (adapted from Scarbrough et al., 2005).

Moisture[a]	Amount	DM loss	CP	NDF	ADF	Lignin
%	mm	% of DM				
76.1	0	0	15.6	71.8	32.4	3.62
	13	- 1.4	15.8	70.8	30.7	3.08
	25	- 0.6	15.9	71.3	33.0	4.43
	38	- 1.6	15.8	70.7	31.0	2.72
	51	- 1.3	15.2	70.8	31.2	3.15
	64	- 0.7	16.1	71.3	31.3	3.76
	76	0.1	15.6	71.9	36.6	5.77
	Effect[b]	Q = 0.01	NS	Q = 0.01	Qu = 0.05	C = 0.02
40.0	0	0	14.9	71.5	31.0	3.03
	13	1.4	14.9	72.6	32.2	3.70
	25	1.5	15.3	72.7	32.7	3.50
	38	2.3	15.1	73.2	33.1	3.84
	51	1.9	15.4	72.9	32.6	3.45
	64	1.4	15.4	72.6	33.1	3.49
	76	3.8	15.0	74.4	33.2	3.59
	Effect	L < 0.01	NS	L < 0.01	C = 0.05	NS
13.0	0	0	15.3	71.4	31.7	3.32
	13	0.8	15.0	72.0	33.0	3.49
	25	2.0	15.5	72.8	33.5	3.85
	38	2.0	15.3	72.9	33.7	3.72
	51	1.8	15.6	72.7	32.9	3.44
	64	2.1	15.6	72.9	33.8	3.71
	76	1.7	16.6	72.7	32.8	3.44
	Effect	Q < 0.01	Q = 0.04	Q < 0.01	Q < 0.01	Q = 0.01

[a] Moisture content of the forage when the simulated rainfall was applied.
[b] Highest order effect of rainfall amount: NS, nonsignificant ($P > 0.05$); L, linear; Q, quadratic; C, cubic; and Qu, quartic.

Table 4. Effects of natural rainfall on the nutritive value of endophyte-infected tall fescue hay at baling. Rainfall events were naturally occurring, and bales were packaged as conventional rectangular bales in Fayetteville, AR during May 2000.[a]

Treatment	Crop Moisture at Baling	Total Rainfall Amount	Number of Rainfall Events[b]	CP	ADIN	NDF	ADF	Lignin	Digestibility[c]
	%	mm	no.	% of DM	% of N	------------------------ % of DM --------------------------			
a	22.5	0	0	7.9	7.1	66.3	37.6	4.81	64.1
b	16.4	0	0	8.2	8.3	67.7	38.3	5.12	62.9
c	9.9	0	0	7.9	8.0	67.3	38.1	4.98	63.9
d	24.6	23	1	8.4	7.7	72.0	40.5	5.48	61.8
e	9.3	71	3	8.6	7.8	76.4	42.6	5.52	59.7
Contrasts									
1) one rainfall event (d) vs. no rain (a, b, c)				NS[d]	NS	< 0.01	< 0.01	0.02	0.08
2) multiple rainfall events (e) vs. no rain (a, b, c)				0.09	NS	< 0.01	< 0.01	0.01	< 0.01
3) one rainfall event (d) vs. multiple events (e)				NS	NS	< 0.01	< 0.01	NS	0.09
4) ideal moisture (b) vs. excessively dry (c)				NS	NS	NS	NS	NS	NS

[a] Adapted from Turner et al. (2003).
[b] Number of rainfall events contributing to the total rainfall prior to baling.
[c] Determined by 48-h ruminal incubation in situ.
[d] NS, nonsignificant (P > 0.10)

Table 5. Effects of natural rainfall during wilting and spontaneous heating during storage on the nutritive value of endophyte-infected tall fescue hay. Rainfall events were naturally occurring, and bales were packaged as conventional rectangular bales and stored for approximately six weeks in small stacks at Fayetteville, AR during 2000.[a]

Treatment	Crop Moisture at Baling	Total Rainfall Amount	Number of Rainfall Events[b]	Maximum Internal bale temperature	CP	ADIN	NDF	ADF	Lignin	Digestibility[c]
	%	mm	no.	°C	% of DM	% of N	------------------ % of DM			---------------------
a	22.5	0	0	49.8	8.9	10.4	74.5	43.4	5.89	59.8
b	16.4	0	0	40.0	8.2	6.4	70.5	41.1	6.20	62.9
c	9.9	0	0	42.8	7.9	7.6	68.1	39.7	5.83	63.2
d	24.6	23	1	50.8	8.6	15.5	78.5	44.4	6.47	59.6
e	9.3	71	3	31.4	7.7	13.0	76.0	44.0	6.83	59.7
SEM				1.3	0.44	1.20	0.71	0.51	0.386	0.75
Contrasts										
1) all damaged hays (a, d, e) vs. no damage (b, c)					NS[d]	< 0.01	< 0.01	< 0.01	NS	< 0.01
2) rain damaged (d, e) vs. no rain (a, b, c)					NS	< 0.01	< 0.01	< 0.01	0.06	< 0.01
3) spontaneous heating (a, d) vs. minimal heating (b, c, e)					0.07	0.01	< 0.01	< 0.01	NS	< 0.01
4) spontaneous heating and rain damage (d) vs. heating only (a)					NS	0.02	< 0.01	NS	NS	NS

[a] Adapted from Turner et al. (2003).
[b] Number of rainfall events contributing to the total rainfall prior to baling.
[c] Determined by 48-h ruminal incubation in situ.
[d] NS, nonsignificant (P > 0.10)

Table 6. Effects of natural rainfall during wilting and spontaneous heating during storage on the voluntary intake, in vivo apparent digestibility, and total tract retention time for growing steers consuming endophyte-infected tall fescue hay. Rainfall events were naturally occurring, and bales were packaged as conventional rectangular bales and stored for approximately six weeks in small stacks at Fayetteville, AR during 2000.[a]

				----------- Intake -----------		------ Digestion Coefficients ----			
Treatment	Crop Moisture at Baling	Total Rainfall Amount	Maximum Internal bale temperature	Diet	Hay	DM	OM	NDF	Total Tract Retention Time[b]
	%	mm	^{o}C	--------- % of BW --------		----------------- % -----------------			h
A	22.5	0	49.8	2.28	2.10	51	53	56	56.5
B	9.9	0	42.8	2.31	2.10	50	52	52	57.6
C	24.6	23	50.8	2.04	1.85	57	60	64	60.9
D	9.3	71	31.4	2.15	1.92	53	56	59	59.2
SEM			1.3	0.057	0.062	1.70	1.63	1.82	3.39
Contrasts									
1) all damaged hays (a, c, d) vs. no damage (b)				0.05	0.09	0.09	0.05	0.01	NS[c]
2) rain damaged (c, d) vs. no rain (a, b)				0.01	0.01	0.03	0.02	0.01	NS
3) spontaneous heating (a, c) vs. minimal heating (b, d)				NS	NS	NS	NS	0.06	NS

[a] Adapted from Turner et al. (2004).
[b] Determined with Yb as an external marker.
[c] NS, nonsignificant (P > 0.10).

Figure 1. Relationship between concentrations of NDF and digestibility (%) for KY-31 tall fescue (adapted from Ball et al., 2002). Source: C. S. Hoveland and N. S. Hill, University of Georgia.

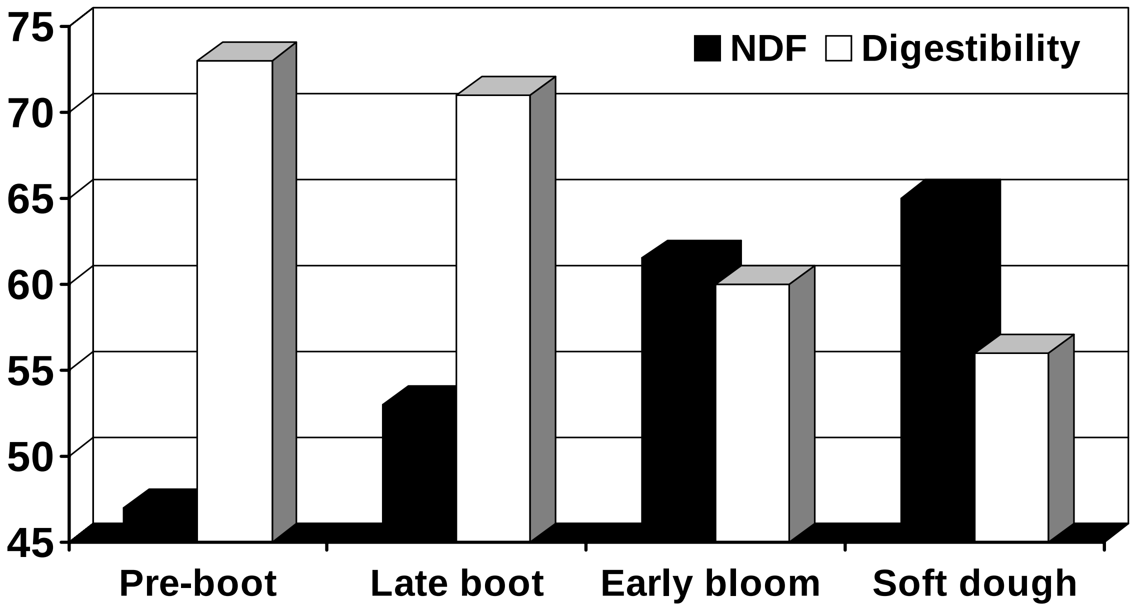

Figure 2. Losses of DM in response to simulated rainfall for vegetative orchardgrass (OG) and bermudagrass (BER) hays damaged by rainfall at ideal moisture concentrations for baling (adapted from Scarbrough et al., 2005).