How to Maximize Energy Content in Forage Grasses

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In a recent paper, Kathryn Watts and Jerry Chatterton (2004) gave an excellent overview of the basic factors affecting carbohydrate levels in forages and how these factors affect forage management.

- Sugars are the substrates for all plant growth, thus, they are critical to plant growth and development.
- Sugars are produced by photosynthesis during daylight.
- At night plants use energy from sugars formed by photosynthesis to grow.
- Whenever the rates of photosynthesis exceed plant growth rates, carbohydrates accumulate.
- At times, plant stresses decrease growth rates more than photosynthesis and carbohydrates accumulate.
- Factors that contribute to plant stress include water and nutrient deficiencies, saline or acidic soils, as well as cold or hot temperatures.
- High concentrations of carbohydrates (sugars, starch, and fructan) can be found in pasture or dry hay of cool-season grasses.

It will be useful to provide some definitions about carbohydrates in grasses. Glucose, fructose, and sucrose), fructans, and starch are all referred to as total non-structural carbohydrates (TNC) (Jensen et al, 2014). Water-soluble carbohydrates (WSC) are defined as the sum of water-soluble sugars, including glucose, fructose, sucrose, and fructans. Since cool season grasses do not accumulate starch except in the seed, WSC and TNC are virtually equivalent values for these grasses. For simplicity, in this paper WSC and TNC will both be referred to as non-structural carbohydrates.

Several studies have reported the benefits of increased non-structural carbohydrate concentrations including increased animal preference (Mayland et al., 2000), increased intake (Burns et al. (2007), and increased animal gains (Gregorini et al., 2006). Increased levels of non-structural carbohydrates in forages is generally considered to be an advantage for livestock, but there are periods in the growing season when increased levels (especially fructans) have been associated with the increased incidence of equine laminitis (Pollitt et al.). Laminitis from cattle grazing grasses high in non-structural carbohydrates is rare.

Non-structural carbohydrates are readily digestible by all mammals (cattle, pigs, humans etc….), but structural carbohydrates (cellulose and hemicellulose) that make up the cell walls (Figure 1) in plants are only digestible by ruminant animals or in the hindgut of horses. Although ruminant animals can digest structural carbohydrates, non-structural carbohydrates are still easier to digest and provide a quick energy source.

In summary, nonstructural carbohydrates in forages vary during the day and night and vary seasonally. They also vary based on forage species, variety, management and environment conditions. Nonstructural carbohydrates are higher in the afternoon than in the morning since photosynthesis occurs during daylight hours. Peak periods of the growing season where nonstructural carbohydrates accumulate occur in the spring and fall. Favorable environmental conditions, such as higher temperatures and rainfall, will utilize non-structural carbohydrates for growth and therefore reduce overall concentrations. Environmental conditions that reduce growth, such as low temperatures and low rainfall, will result in nonstructural carbohydrate accumulation, as long as the plant is still photosynthetically active. Long periods of sunny weather typically cause nonstructural carbohydrate accumulation while long periods of cloudy weather typically reduce the amount of nonstructural carbohydrates. There are significant species and variety differences as well, and some breeders are developing cultivars for high or low non-structural carbohydrate concentrations. Management of pastures will also affect non-structural carbohydrate concentrations. Pasture management that stimulates growth, such as grazing or fertilizer applications, can result in reduced non-structural carbohydrates, while pasture management that reduces growth, but does not affect photosynthesis can cause non-structural carbohydrate accumulation.

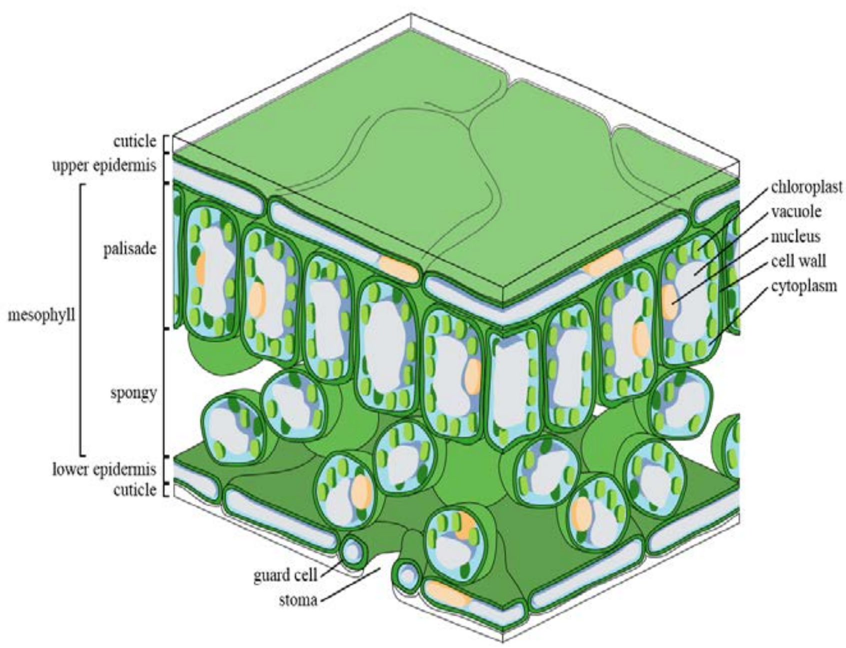

Figure 1. Cross-section of a plant leaf showing the cell walls with structural carbohydrates and the cell contents that can contain high levels of non-structural carbohydrates.
http://commons.wikimedia.org/wiki/File:Leaf_Tissue_Structure.svg

Kelly Prince's recently completed her master's research at the University of Kentucky in Lexington, KY. She determined the non-structural carbohydrate concentration of four cool season grasses during the 2015 growing season in a replicated research trial. Kelly managed the stand by cutting every two weeks in the spring and early summer and every month in the late summer to represent a well-managed pasture. Averaged across the whole growing season she showed that the highest non-structural carbohydrate levels were from perennial ryegrass, followed by tall fescue, KY bluegrass, and orchardgrass (Figure 2). Interestingly, one variety of perennial ryegrass called 'Aberzest' was almost always the highest and the three varieties of orchardgrass were usually the lowest.

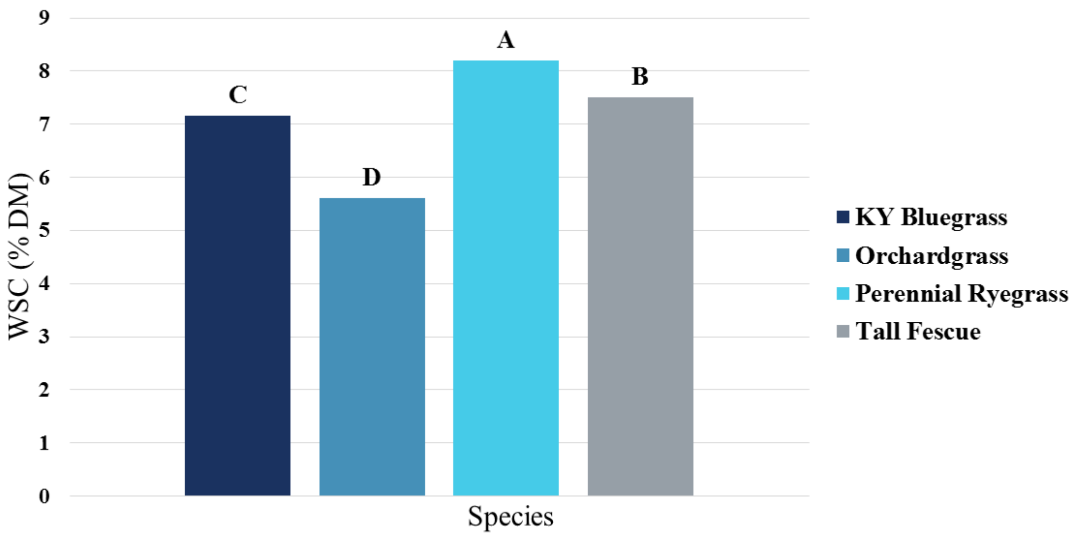

Figure 2. Species Effect on WSC (%DM) from May to November 2015

Kelly also showed that afternoon harvested cool season grasses had higher levels of non-structural carbohydrates that the morning harvests, regardless of the grass species or variety or the addition of nitrogen (Figure 3). The higher afternoon levels compared to morning levels continued throughout the growing season, with the highest levels occurring in the spring and fall and the lowest levels during the summer. This makes sense, because cool season grasses grow more efficiency during cooler temperatures, therefore they have more photosynthesis and produce more sugars. Additionally, there is less respiration during cooler temperatures, so less carbohydrates are burned off to supply energy.

It's interesting that the morning and afternoon non-structural carbohydrate levels are very close on July 8 and September 15. After reviewing the weather conditions during and before these days these results are not surprising. On July 15 there was a solid cloud cover the majority of the day resulting in less photosynthesis and therefore less production of carbohydrates. The night before September 15 was unseasonably cool, therefore there was little drop in carbohydrates overnight.

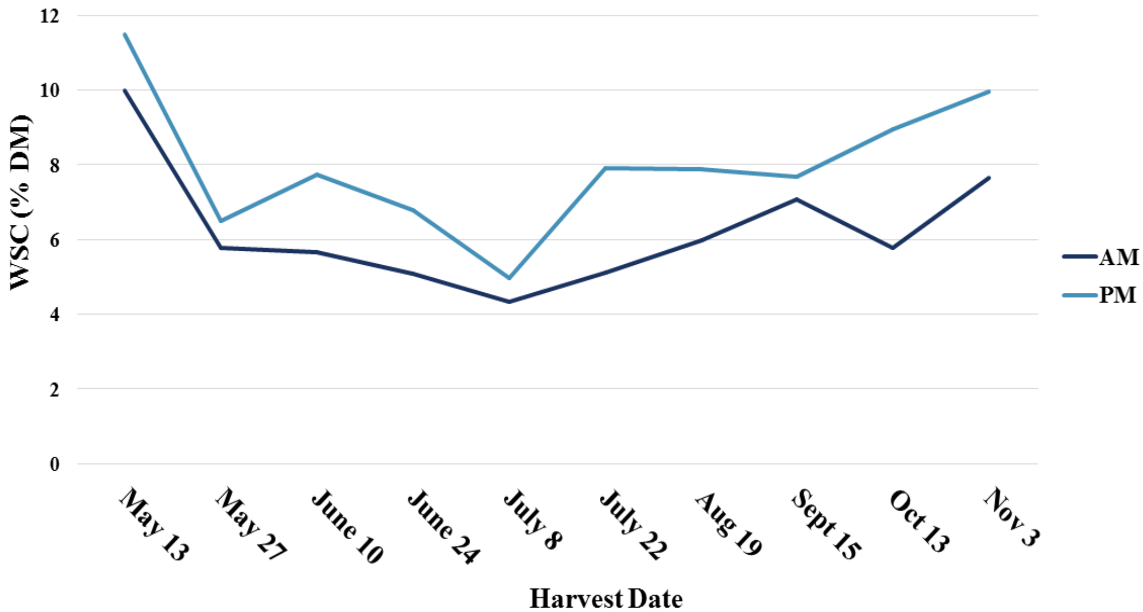

Figure 3. Seasonal and Diurnal Variation of water soluble carbohydrates (WSC) in cool-season grasses.

Kelly's research also showed inconsistencies in non-structural carbohydrate levels following nitrogen applications. Sometimes there was a drop in carbohydrates for a few weeks after applying nitrogen, especially with perennial ryegrass and Kentucky bluegrass. This does not seem to make sense, since nitrogen helps grass to grow, but rapidly growing grass uses up carbohydrates for growth. Also, the addition of nitrogen causes higher protein levels, which require energy to be produced and displace some of the non-structural carbohydrates.

When shown individually, the differences in non-structural carbohydrates between grass species were significant, especially in the early spring with the perennial ryegrass varieties (cultivars) sometimes having twice the levels of orchardgrass. Tall fescue and KY bluegrass showed non-structural levels in-between the other two grasses (Table 1). When you look at these numbers, it would appear that all Kentucky cattlemen should be planting perennial ryegrass. Perennial ryegrass though is not that well adapted to our hot and often dry growing conditions during the summer. It is usually only productive for two years in Kentucky and then the stands thin rapidly. Additionally, even during those first two years, summer production is low. With it's high non-structural carbohydrate levels, perennial ryegrass could have a fit for cattle producers raising grass-finished beef. Some of the grass based dairy producers in the state plant a portion of their pasture with perennial ryegrass because the nonstructural carbohydrate levels increase milk production and the added milk production outweighs the frequent replanting.

Since perennial ryegrass had limitations in the state, tall fescue is the next best option with good survival, high productivity, and reasonably high non-structural carbohydrate levels. The new novel endophyte varieties have the additional advantage of a beneficial fungal endophyte promoting plant survival and growth, without the negative implications of harmful ergot alkaloids. Kentucky bluegrass is also a high quality grass, but it's lack of summer production make it a less desirable forage when planting new pastures. Existing pastures that contain significant amounts of KY bluegrass can produce good animal gains.

Table 1. Non-structural carbohydrate content for KY bluegrass, orchardgrass, perennial ryegrass and tall fescue when harvested in the morning (8 to 9:00am) and mid-afternoon (3 to 4:00pm).

Species	Cultivar	Time of Day	May 13	May 27	June 10	June 24	July 8
KY Bluegrass	Ginger	AM	11.93^{E}	6.62^{DE}	6.10^{FGH}	5.40^{FGH}	4.77^{EFG}
		PM	13.35^{CD}	6.74^{DE}	7.98^{C}	7.42^{BC}	5.20^{BCDE}
Orchardgrass	Persist	AM	7.63^{K}	3.48^{I}	4.52^{L}	4.04^{I}	3.48^{K}
		PM	8.76^{GHI}	5.35^{H}	6.61^{DEF}	5.66^{EF}	3.89^{IJK}
	Profit	AM	6.72^{L}	3.85^{I}	4.61^{L}	3.84^{I}	3.66^{JK}
		PM	7.83^{JK}	5.17^{H}	6.33^{FG}	5.55^{EFG}	4.31^{GHI}
	Quickdraw	AM	6.08^{L}	3.78^{I}	4.73^{KL}	3.91^{I}	3.55^{JK}
		PM	8.13^{IJK}	5.40^{GH}	6.40^{EFG}	5.73^{EF}	4.04^{HIJ}
Perennial Ryegrass	Aberzest	AM	14.06^{BC}	8.74^{AB}	8.17^{C}	7.02^{CD}	5.48^{BCD}
		PM	15.18^{A}	9.32^{A}	9.73^{A}	8.60^{A}	6.17^{A}
	Calibra	AM	14.44^{AB}	8.10^{C}	7.04^{DE}	5.94^{E}	5.01^{CDE}
		PM	14.96^{AB}	8.23^{BC}	8.65^{BC}	6.98^{CD}	5.58^{B}
	Linn	AM	12.97^{D}	6.34^{EF}	5.20^{JK}	5.71^{EF}	4.96^{DEF}
		PM	13.60^{CD}	6.65^{DE}	7.22^{D}	6.73^{D}	5.41^{BCD}
Tall Fescue	Bronson	AM	9.46^{GH}	5.94^{F}	5.85^{GHI}	5.31^{FGH}	4.35^{GHI}
		PM	11.81^{E}	7.00^{D}	8.90^{B}	7.69^{B}	5.51^{BC}

While Kelly's research showed differences in non-structural carbohydrates her study was a small plot agronomic trial, therefore the effects of these levels on animal behavior or animal production were not measured. Henry Mayland and other researchers (2000) in Utah conducted an interesting project to see if cattle showed any difference in preference between eight tall fescue varieties based on carbohydrate content. They showed that cattle preferred those varieties that produced the highest levels of total nonstructural carbohydrates (Tables 2-3). Right now most tall fescue varieties are not marketed based on carbohydrate content, but this may be a factor to consider in the future. Currently DairyOne will provide water soluble carbohydrate levels on samples that you submit to them for forage quality testing.

Table 2. Cattle preference scores for tall fescues grazed in each of four seasons and 2 year, where 0 shows no evidence of grazing and 10 indicates that all available forage was eaten.

	Preference							
	1993				1994			
Cultivar	**May**	**June**	**Aug.**	**Sept.**	**May**	**June**	**Aug.**	**Sept.**
Kenhy	**7.1**	**6.4**	**8.6**	**7.7**	**6.8**	**8.8**	**8.6**	**8.2**
Kentucky-31	**5.3**	**3.9**	**7.1**	**5.2**	**3.9**	**7.3**	**6.9**	**6.6**
HiMag	**4.5**	**4.0**	**7.4**	**4.4**	**3.8**	**6.6**	**6.6**	**6.5**
C-1	**6.6**	**3.9**	**5.6**	**5.3**	**4.0**	**5.9**	**5.9**	**5.0**
Stargrazer	**4.0**	**3.7**	**6.8**	**4.2**	**3.7**	**6.4**	**6.5**	**6.8**
Barcel	**4.5**	**3.3**	**6.4**	**4.0**	**2.9**	**6.5**	**6.4**	**6.8**
Missouri-96	**4.6**	**3.1**	**6.5**	**3.4**	**2.9**	**5.8**	**5.7**	**5.4**
Mozark	**3.9**	**2.4**	**6.1**	**2.9**	**1.9**	**6.3**	**6.4**	**6.8**

Table 3. Total nonstructural carbohydrate (TNC) concentrations [g/ kg SDM (structural dry mass)]† by cultivar, harvest month, and year.

	1993					1994					
Cultivar	May	June	Aug.	Sept.	$\bar{X}$ 1993	May	June	Aug.	Sept.	$\bar{X}$ 1994	$\bar{X}$ 1993–1994
Barcel	160	114	106a	129	127a	122	131b	79cd	156abc	122ab	125
C-1	141	122	112a	129	126a	105	154a	86bc	155abc	125ab	126
HiMag	154	133	114a	130	133a	119	160a	81c	162abc	131ab	132
Kenhy	143	130	108a	141	131a	112	168a	103a	192a	144a	138
KY-31	162	125	115a	124	132a	126	168a	87bc	151bc	133ab	133
MO-96	153	117	105a	121	124ab	116	125b	75cd	135cd	113bc	118
Mozark	140	108	91b	116	114b	113	113b	68d	114d	102c	108
Stargrazer	154	129	109a	136	132a	129	165a	101ab	177ab	143a	138

† Means in a column followed by letters in common are not different by Duncan's multiple range test ($P < 0.05$).

Dr. P. Gregorini and others (2006) conducted a very interesting study related to carbohydrate content in forage grasses in Argentina using annual ryegrass. This study was entitled: "Timing of herbage allocation in strip grazing: Effects on grazing pattern and performance of beef heifers." Their objectives were to analyze grazing behavior and performance of beef heifers when they were given a strip of fresh ryegrass in the morning at 7:00am (MHA) or in the afternoon at 3:00pm (AHA). They took very detailed measurements including: grazing, rumination, and idling times during daylight hours, as well as bite rate, average daily gain, change in body condition score, and daily herbage dry matter intake.

Their results showed that beginning in week 4 of the winter grazing period, heifers turned into a new paddock in the afternoon gained 0.3 lbs more per day than the heifers turned in in the morning. In the spring, the afternoon turn-in heifers produced 1.2 lbs more gain per day than the morning turn-in group during the entire 6 week grazing period (Figure 4). These added gains for the afternoon turn-in group were the likely the result of two main factors: The non-structural carbohydrate content was significantly higher in the afternoon (Table 4) and those heifers turned in in the afternoon showed more concentrated grazing time in the evening and had a higher bite rate. In other words, when heifers were turned into fresh forage in the afternoon then their afternoon/evening grazing period became longer and was more intensive. And this coincided with the time period when the forage had the highest nutritive value.

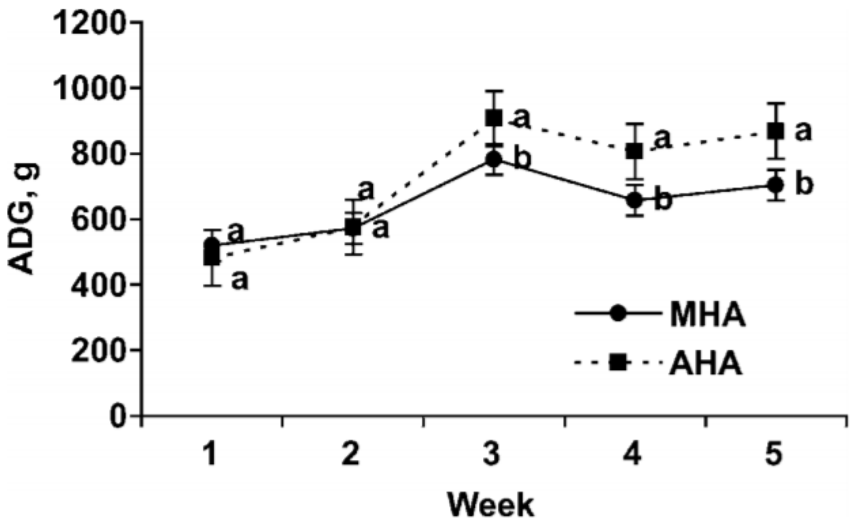

Figure 4. Average daily gain of beef heifers strip grazing during daylight in winter with morning turn in (MHA: 7:00am) or afternoon turn in (AHA; 3:00pm).

Table 4. Variation in chemical composition (% of DM) during daylight hours of herbage consumed by beef heifers strip grazing on annual ryegrass pasture. Specifically note the non-structural carbohydrate (NSC) values.

Variable	IVDMD			NDF			NSC[2]			CP		
Season	Winter	Spring	SE	Winter	Spring	SE	Winter	Spring	SE	Winter	Spring	SE
Time of day												
0700	79^{ax}	72^{bx}	2.4	50^{x}	46^{x}	2.2	13.6^{x}	10.3^{x}	2.78	15.2	14.4	1.02
1300	81^{axy}	74^{bxy}	2.4	47^{y}	43^{xy}	4.2	18.1^{y}	16.2^{y}	2.78	13.2	12.4	1.22
1900	83^{ay}	75^{by}	2.5	46^{z}	40^{y}	4.3	20.3^{y}	16.3^{y}	2.85	14.3	12.9	1.41
SE	1.7	1.7		3.0	3.0		1.97	2.01		1.5	1.4	

[a,b]Within a variable and row, means with different superscript letters differ ($P < 0.05$).

[x–z]Within a variable and column, means with different superscript letters differ ($P < 0.05$).

[1]Values are the mean of 3 dates pooled across 4 animals.

[2]Nonstructural carbohydrates.

Besides Kelly's recent work there have been numerous research studies over the years on non-structural carbohydrate levels in grasses. One of the most exhaustive was conducted by Kevin Jensen and his colleagues (2014). The complete paper presents numerous tables, but the table on total nonstructural carbohydrates provides an excellent overview of the ranking between multiple cool season grass species (Table 5).

Table 5. Means and trends in total non-structural carbohydrate (TNC) concentration of 15 grass dates, combined across 2 yr in northern Utah.

Species	Overall mean	Sampling dates							
		3 May	18 May	2 June	8 July	3 Aug.	15 Sept.	5 Oct.	2 Nov.
	g kg^{-1} DM								
Cool-season grasses									
Perennial ryegrass	223.5	216.9	303.6	324.2	138.9	113.9	166.4	260.9	263.1
Timothy	189.6	176.1	198.3	210.1	116.5	141.6	156.4	239.7	278.5
Crested wheatgrass‡	186.5	219.8	227.3	221.0	124.7	123.7	156.1	230.6	191.0
Creeping meadow foxtail	164.0	196.9	170.5	178.9	126.2	125.1	148.2	206.2	160.3
Tall fescue	158.5	162.3	163.2	179.2	125.3	109.8	144.3	189.2	194.4
Orchardgrass	152.0	178.0	185.6	175.2	95.4	62.5	123.7	185.9	210.1
Kentucky bluegrass	150.9	244.1	188.9	204.9	95.4	109.4	109.7	155.6	99.8
Intermediate wheatgrass‡	147.9	189.6	160.8	177.0	106.9	87.7	124.7	165.9	170.9
Smooth bromegrass‡	138.6	179.2	168.1	140.6	98.5	90.0	138.1	180.8	113.4
RS wheatgrass hybrid‡	133.7	159.2	149.3	153.0	93.4	94.4	118.5	169.0	133.0
Tall wheatgrass‡	131.5	137.6	129.6	154.2	87.3	83.6	119.0	168.8	172.6
Meadow bromegrass§	124.2	155.4	130.1	127.0	86.6	72.8	117.5	167.7	136.1
Sandberg bluegrass‡	114.5	129.2	136.7	158.7	87.4	104.4	92.9	119.5	87.5
Mean	**155.1**	**182.4**	**178.5**	**183.0**	**106.0**	**99.1**	**132.2**	**188.8**	**170.7**

In conclusion, non-structural carbohydrates are produced by photosynthesis in cool season grasses and their levels vary based on species, variety, management, season, time of day, environomental conditions, and other factors. Recent research at the University of Kentucky showed that perennial ryegrass had the highest levels, followed by tall fescue, KY bluegrass and orchardgrass. This species ranking may change based on location and pasture management.
Other studies have reported the benefits of increased non-structural carbohydrate levels in cattle including increased animal preference, increased intake, and increased animal gains.

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