DIURNAL CHANGES IN FORAGE QUALITY AND THEIR EFFECTS ON ANIMAL PREFERENCE, INTAKE, AND PERFORMANCE

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ABSTRACT

Net photosynthesis, respiration and translocation in growing plants cause a circadian rhythm in forage quality. Soluble sugar concentrations increase in plants during the day causing a dilution in ADF and NDF and an increase in RFQ and RFV. Herbivores show a strong preference for afternoon (PM) vs morning (AM) harvested forage. Cattle, sheep, goats, horses and rabbits are able to distinguish between two similar hays that differ by as little as 0.5% soluble sugar. Dairy cows fed total mixed rations containing 50% Idaho grown alfalfa produced 6% more milk when the hay had been cut in the afternoon vs. cut in the morning. No difference in milk production was measured when cows were fed the PM- and AM-cut Wisconsin hays. Sheep and rabbits have a strong preference for PM vs. AM-cut alfalfa but when not given a choice, they eat the same amount of each hay. During the spring season, cattle in 24 h strip grazing studies in Argentina, gained more weight (2.5 vs. 1.2 lbs./d) when given access to fresh pasture each afternoon (3 pm) compared to those given access each morning (7 am). Extrapolating the benefit of afternoon swathing to 25% of the alfalfa in the western United States has an annual value of nearly $300 million. Continued research is needed to identify conditions where these management strategies would be appropriate.

Key Words: forage, diurnal-quality, animal preference, animal production

INTRODUCTION

Soluble sugars like glucose, fructose, and sucrose are produced by photosynthesis in growing plants. Approximately one-third of the sugar provides the energy needed for water and nutrient up take, one-third is lost via respiration, and the remaining third is used for plant growth. During the day, photosynthesis causes a net increase in the concentration of soluble sugars within the leaves, but at night when photosynthesis is no longer possible; there is a net decrease in soluble sugar concentration. This diurnal cycling of sugars in plants is illustrated in Figure 1. Our line of investigation is to characterize possible diurnal cycling of soluble sugars in various forages and to determine if herbivores can detect these diurnal differences in TNC and will adjust their intake of forage and nutrients and further will that affect their overall production. We will summarize some of our experiences in this extensive series of studies.

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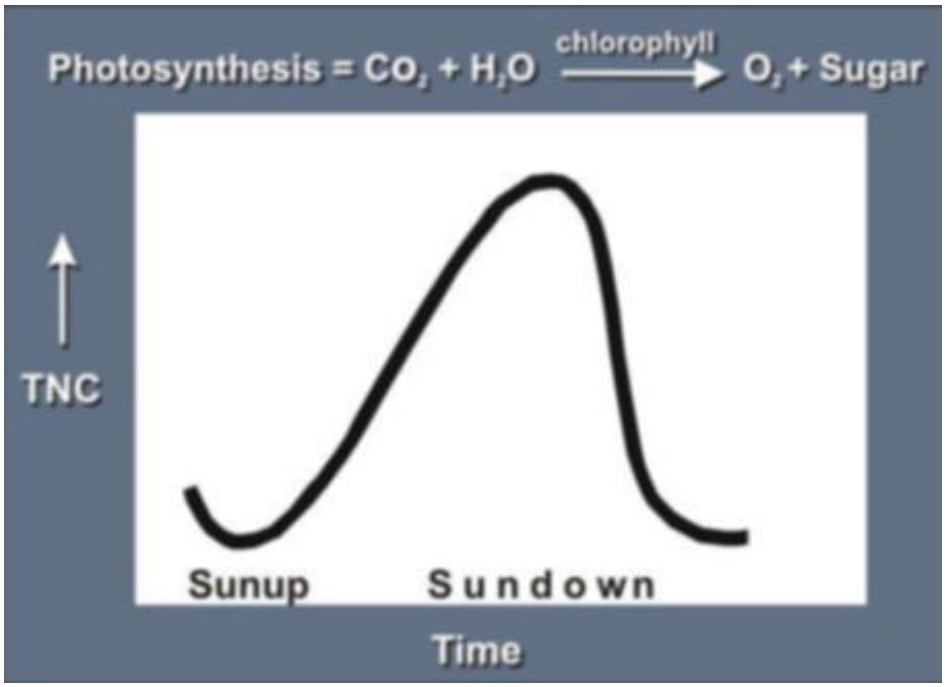

Figure 1. Diurnal changes in total non structural carbohydrates (TNC) in forages. Minimum concentrations of TNC occur at about sunup and maximum occur at about sundown. The height of the curve depends on the forage type, solar radiation levels and temperature.

SOLUBLE SUGARS AND FORAGE QUALITY

Many grasses will have similarly shaped daily TNC-accumulation curves, yet some varieties may be significantly different than others. The different varieties will have diurnal curves like the one shown in Figure 1, but some will have curves that fall above others. This was demonstrated in tall fescue when one variety was shown to have significantly higher TNC at all times during the day than did others (Shewmaker et al. submitted). These differences led British scientists (Orr et al, 1997) to select a perennial ryegrass having a higher soluble carbohydrate concentration than other existing varieties. This selection was superior to others for its increased animal productivity.

Most of the plant's photosynthetic activity occurs in the leaves. Stems of forbs, or pseudostems in grasses have some photosynthetic activity, but serve as intermediate storage sites as sugars move to roots or are respired. Concentrations of TNC in the leaves demonstrate the diurnal cycling as shown in Table 1 where orchardgrass leaves and pseudostems were clipped at 0700 h in morning and again at 1900 h in evening. Leaves increased in starch and TNC during the day while there was no change in the pseudostems. The increased sugars in the leaves accounted for a significant decrease in neutral detergent fiber (NDF) and crude protein (CP) simply because of dilution by the extra sugar in the 1900-pm material (Griggs et al. 2002).
Table 1. Quality factors measured in orchardgrass canopy following sequential top removal (Griggs et al., 2005).

Factors	Leaves (27 – 40 cm height)		Pseudostems (8 – 12 cm height)	
	0700 am	1900 pm	0700 am	1900 pm
Starch, g/kg	6	32**	19	24
TNC, g/kg	69	160**	65	75
NDF, g/kg	427	414**	606	594
ADF, g/kg	237	234	342	335
CP, g/kg	281	248*	138	152
IVTDMD, g/kg	914	923	796	817

**, ** Mean differences between 0700 am and 1900 pm are significant at P <0.05 and 0.01.*

Forage quality of afternoon (PM-cut) harvested and subsequent morning (AM-cut) harvested hay has shown that other components may change in addition to the sugars. The increased mass of the sugars in the PM-cut hay results in reducing NDF, acid detergent fiber (ADF), crude protein (CP) and nitrates (NO_3-N as shown in alfalfa (Table 2). The gain in *in vitro* dry matter digestibility (*IVDM*) is attributed to the reduced concentration of these components but also to the significant increase in TNC throughout the day.

Table 2. Composition of alfalfa hays fed to cattle in preference study (Fisher et al., 2002).

	NDF	ADF	Lignin	IVDMD	CP	NO_3-N	TNC
	---------- g/kg ----------						
PM-cut	399	304	64	782	225	0.75	56.2
AM-cut	418	320	69	760	220	0.84	46.1
PM vs. AM (*P > F)*	< 0.01	< 0.01	< 0.01	< 0.01	< 0.20	< 0.01	< 0.01

ANIMAL PREFERENCE

We find it amazing that many herbivores are able to differentiate between hays cut at sundown from hays cut the next morning at sunup. Some of you may have seen the time-lapse video showed at our 1998 meeting held in Reno (Mayland et al., 1998) It was entertaining to watch the steers move into the stanchion containing two tubs of hay. One tub would contain a PM-cut hay while the second tub would contain an AM-cut hay; each presented in randomized order. The animals preferred the PM-cut hay and would resist attempts to move them to the AM-cut hay. We have since documented preference for PM- vs Am-cut hay by cattle, sheep and goats (Fisher et al., 1999, 2002, 2005; Burns et al., 2005); by rabbits (Mayland et al., unpublished), and horses (Mackay et al., 2003). Earlier, grazing preference studies concluded that TNC was a cue used by the cattle grazing a several tall fescue varieties (Mayland et al., 2000).

What controls the animal sensitivity to the afternoon cut hay? We earlier examined the volatile compounds that come from freshly cut or cured hay of eight different tall fescue varieties that had been scored for grazing preference (Mayland et al, 1997, 2000). These preference scores were related positively to several compounds that made up a small portion of the total volatiles. Perhaps these compounds serve as a natural cue to the forage components that are associated with

previous responses to selecting such hays. A study conducted in Australia showed that after sheep had 3-4 h access to both PM- and AM-cut oat hay (these sheep had never eaten oat hay before) preferred the PM- to the AM- cut hay. However one sheep preferred the AM-cut and two sheep did not differentiate between the PM- and AM-cut forages.

Table 3. Forage intake by steers offered PM or AM harvested tall fescue grass or alfalfa (Fisher et al., 1998).

		ADF	NDF	TNC	DMI
		---------- % ----------			-- g --
Tall Fescue	PM	25.1	48.2	9.23	1078
	AM	26.5	50.8	7.42	762
Alfalfa	PM	30.3	39.7	5.33	987
	AM	31.3	40.6	4.30	758

If the PM-cut forage contains more sugar than the AM-cut; why not just add sugar to the AM-cut to make it test like the PM-cut hay. This hypothesis was tested with sheep using PM- and AM-cut alfalfa. Sufficient sugar was added to the AM-cut hay so it would test like the PM-cut hay. Burrett et al. (2005) concluded that lambs preferred hay cut in the evening to hay cut in the morning but adding sugar to the AM-cut hay did not account for this preference until lambs learned about the benefits of added sugar. This study and others on AM-PM hay emphasizes that ruminants prefer forages based on small changes in plant chemistry that are difficult to detect in the lab. Thus, it is important that animal preference is determined with feeding trials and not to rely on forage chemical composition of predict forage preference.

ANIMAL PRODUCTION RESPONSES TO CUT HAY

We conducted two animal production studies to compare PM-cut with AM-cut alfalfa hay. This interim report will be rather sketchy be neither study is complete. A dairy lactation study was conducted at the US Dairy Forage Research Center in Madison, WI. The total mixed ration (TMR) contained 50% alfalfa cut in PM and AM in both Idaho and Wisconsin. Results indicate a 6% yield increase of feeding the PM-cut vs. the AM-cut Idaho hay, but no difference when feeding the Wisconsin hay (Table 5). This increased lactation response verifies earlier estimates of lactation response to PM-cutting of hays produced in the western U.S. of this magnitued Forage chemical composition and milk components are not yet available to possibly explain these results.

Table 4. Milk production by cows fed 16 weeks in switch back design (within alfalfa source)with a total mixed ration (TMR) containing 50% alfalfa produced in either Idaho or Wisconsin and cut at sundown or sunup. Preliminary data from study by DM Mertens and HF Mayland.

Hay source	Milk yield, lbs/d		Probability, *P*
	TMR with PM-cut alfalfa	TMR with AM-cut alfalfa	
Idaho	83	88	<0.01
Wisconsin	93	92	0.28

Lambs were fed a total mixed ration containing either PM-cut or AM-cut alfalfa hay from Idaho. These animals had been on summer range and were started on a conditioning ration in preparation for breeding. Preliminary results show that animals receiving the PM-hay ration had significantly less refusals than animals receiving the AM-hay. Total feed consumption and weight gain for the 35 day period were not different.

CATTLE RESPONSES TO MANAGED STRIP GRAZING

The diurnal cycling of forage quality can also lead to grazing behavior that responds to the increased concentration of sugars in the plant during afternoon and early evening (Gregorini et al. (manuscript submitted). The study was conducted on the flooded Pampa range of Argentina which accommodated yearlong grazing. The pasture was largely annual ryegrass having the herbage characteristics shown in Table 5. These heifers were continually on pasture which was managed by 24-h strip grazing. Two treatments were tested. In the first, animals were moved to new pasture every 24-h at 7am. In the second treatment, animals were moved every 24-h at 3pm. Logistics required that forage samples were taken at 7am and 7pm. Forage (Table 5) sampled at 7pm compared to 7am, contained more non structural carbohydrate (NSC) and reduced concentrations of CP and NDF. The net result was a greater *In vitro* dry matter digestibility (IVDMD). This resulted in greater weight gain (Table 6) in animals that were moved at 3pm in contrast to those moved at 7am each 24-h. Animals accessing fresh pasture in the afternoon were ingesting grass leaves that had saturated with soluble sugars and so these animals were eating a very rich feed. Those turned onto new pasture each morning, grazed foliage containing a minimum of NSC. The animals continued to eat the leaves and thus prevented the accumulation of sugar.

Table 5. Diurnal changes in pasture herbage characteristics (g/kg). Preliminary data from P.Gregorini et al.

Season	CP		NDF		NSC		IVDMD	
	7am	7pm	7am	7pm	7am	7pm	7am	7pm
Winter	152	143	500	460	136	203	790	830
Spring	144	129	460	400	103	163	720	750

Table 6. Beef heifer growth responses to grazing morning or afternoon accessed fresh-daily pasturage. Preliminary data from P.Gregorini et al.

Season	Weight gain, kg/d		Significance
	3 PM turn on	7 AM turn on	P – value
Winter	0.73	0.66	< 0.01
Spring	1.14	0.56	< 0.03

ECONOMIC VALUE OF THIS TECHNOLOGY

Afternoon versus morning forage harvesting' technology in Western US is projected to have a value of nearly $300,000,000 Three different approaches were used in making these computations. Assuming a 5% increase in forage value for alfalfa in 17 western states (west of the 100th meridian) would be about $100 million annually (see #1). The increased return based on forage quality changes (see #2) would be $44 to $127 million annually (see #2). A 5% increase in projected milk production at today's prices, would increase economic return by $276,000,000 (see #3) in western US.

1. Impact calculated on 5% increased forage value.

Of the approximately $2 billion alfalfa produced annually in Western states, one-half may be cut in morning. Cutting that alfalfa in afternoon would increase the hay value by 5% or $100,000,000+.

2. Impact calculated on NDF and R.Q. values of three PM vs AM cuttings of alfalfa hay at Kimberly.

About 40 million ton alfalfa is produced in 11 western states. Assume ½ cut in morning. W. Weiss (OARDC) estimates $2.40 - 3.40 /T for each 1% decrease in NDF. This computes at $44 to 68 m annually. SDSU estimates $0.90/t for each unit increase in R.Q. = $127 m annually.

3. Impact on annual milk production.

About 85 billion lbs. of milk is produced west of 100th meridian. Assume a 5% increase by cutting all alfalfa in afternoon. Further assume a milk price of $13/cwt . Adopting this technology would increase returns by $ 276 million.

IMPLEMENTATION OF THE 'PM' TECHNOLOGY

- Determine time needed to swath the hay for that day and center the swathing time on sundown.
- Over night drying of the swathed hay is beneficial, but you may not count on it.
- If the intent is to swath between about 2 am and noon, plan to keep that hay separate as it will have lower test value than hay swathed in afternoon.
- Hay intended for the horse market should be cut when TNC's are minimum. Some of the sugars may contribute to laminitis.
- Reduce risk of high nitrate nitrogen values in forages (10-15%) by harvesting near sundown. The limit of 1000 ppm NO_3-N may restrict imports of some alfalfa into Japan.
- Swath hay in afternoon when top dressing bunkers or mixing in feed wagon for evening and next morning's feeding.
- When using a 24-h strip grazing system, move animals in late afternoon rather than morning. The animals turned onto new pasture in late afternoon will have an extended grazing period following turnout.
- Shading forage will result in reduced sugar accumulation
- PM- vs. AM-cut forage may have less advantage in 'hot TMRs'
- PM-vs. AM-cut silage/haylage may ferment more rapidly. That may be an advantage for alfalfa silage.

SUMMARY

Net photosynthesis often causes an accumulation of soluble sugars in forages. These daily increases often serve as cues to both grazing animals and animals fed harvested forages. The enrichment of soluble energy in the afternoon-harvested forage may represent a 5% increase over rations containing morning-cut forage. The technology, if applied in the western US may have a net value of nearly $300 million annually for the dairy industry alone. Research is needed to quantify respiration losses to drying and storage. Harvest hay in the afternoon or consider afternoon turnout and pasture rotation if you use a strip grazing system. These management systems have great potential to increase profit margins in agriculture.

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