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# NONSTRUCTURAL CARBOHYDRATES: CHALLENGES AND PROGRESS IN FORAGE TESTING

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## *Introduction*

Forage testing has evolved by adapting new technology but acceptance of different tests for forage quality is slow and some tests are impractical. Reliance on technology has replaced intuition and experienced knowledge in some cases. For example, alfalfa grown at high elevations was preferred as dairy hay in the 1960's and 1970's. The use of forage testing in the 1980's and 1990's appears to favor alfalfa hay grown at lower elevations. Moreover, the forage tests of acid detergent fiber (ADF) and neutral detergent fiber (NDF) do not consistently predict animal intake or performance across cuttings. For example, hot season cuttings usually have finer stems, are greener in color, and conventional tests show similar values of ADF and NDF to first (cool season) cuttings, yet animal intake is less for the hot-season cuttings. Using current forage testing to compare high versus low elevation grown hay, or to compare hays from different cuttings, is not dependable. There are some promising developments which should improve our ability to predict animal performance. The testing for nonfibrous carbohydrates (NFC) or total nonstructural carbohydrates (TNC) are additional tools you may want to use. Nonfibrous carbohydrates are defined by the National Research Council (2001) as NFC = 100 - (%NDF + % CP + %Fat + %Ash), where CP is crude protein. Total nonstructural carbohydrates are determined by a fractionation of the sample and are calculated as the sum of monosaccarhides, disaccharides, short chain polysaccharides, and starch. This paper reviews the underlying principles of forage quality and the development of testing; environmental, genetic, and harvest management effects on forage quality; and reviews diurnal cycling of total nonstructural carbohydrates and related animal preference studies.

## Forage Testing Development

The "proximate analysis" procedure used in the 1960's characterized forage quality by crude fiber, ether extract, nitrogen-free extract, and crude protein. These values were adjusted by digestion coefficients and summed to total digestible nutrients (TDN). The "energy system" was developed in the 1970's and was more accurate at predicting performance, but is not practical for application because of the time and cost of analysis (oxygen bomb calorimetry). An improved analysis of fiber was developed by Van Soest which determined ADF and NDF (Goering and Van Soest, 1970). Current procedures for NDF, ADF, and lignin are described by Van Soest et al. (1991). However, ADF was developed by Van Soest as an intermediary residue to determine lignin, cellulose, Maillard products, silica, acid insoluble ash, and acid detergent insoluble N. Van Soest et al., (1991) concluded that there is no valid theoretical basis to link ADF to digestibility, even though there may be an association

alfalfa at the vegetative to bud stage, it will often recover yield when watered and maintain a good leaf to stem ratio.

### *Genetic Effects*

A common hypothesis is that an alfalfa canopy, if stand is adequate, will develop to a point when maximum radiation is intercepted. Beyond that point, the lower leaves will senesce. Another theory is that selection for higher yields without consideration of forage quality, merely increases the internode length. Demment et al. (1986) concluded that forage quality can be increased simultaneously with forage yield. Their data suggests that larger plants did not require a higher concentration of fiber for structural support.

### *Harvest Management Effects*

To produce premium quality hay, alfalfa should be cut at an early maturity (pre-bud stage). Harvest management such as the time of day the forage is cut and the rate of hay dry-down can also affect forage quality. Alfalfa accumulates total nonstructural carbohydrates (TNC) during daylight because photosynthesis produces TNC more rapidly than they are exported and utilized for new growth and maintenance. Total nonstructural carbohydrates are composed of starch, fructans, sucrose, glucose, and fructose. Continued plant respiration during darkness depletes TNC concentration. After hay is cut, plant and microbial respiration will continue to consume TNC until the hay reaches less than about 16% moisture. Therefore it is important to dry the hay as quickly as possible to retain as much TNC as possible, as well as avoiding rain showers and allowing the next crop to grow.

### *Diurnal Cycling of Total Nonstructural Carbohydrates (TNC)*

A study reported by Fisher et al. (2002) documents the diurnal variation of TNC. Germain 'WL 322HQ' alfalfa was sampled at 3-hour intervals during the 24-hour period prior to cutting. A 10-acre grower's field near Kimberly, ID was sampled along a transect midway in the field and perpendicular to irrigation furrows. Sampling by compositing 10 grab-samples per plot immediately preceded first and fourth cuttings in 1997. Samples were freeze-dried and ground in a cyclone abrasive mill to pass a 1mm screen. The TNC concentrations were predicted by Near Infrared Reflectance Spectroscopy (NIRS). The calibration of TNC was determined by an adaptation (Fisher & Burns, 1987) of the wet chemistry method described by Smith (1969).

The TNC curves were sinusoidal over a 24-h period (Figure 1), but linear between 0900 (Figure 2) and about 1800 Mountain Daylight Time. On May 26 the TNC increased linearly from 5.8 % of plant dry matter (DM) at 0900 (harvest hour = 0) to 2100 MDT at the rate of 0.29 % TNC per hour. On Sept. 22 the TNC increased linearly from 5.4 % at 0900 (harvest hour = 0) to 1930 MDT at the rate of 0.5 % per hour, an increase of 193 %.

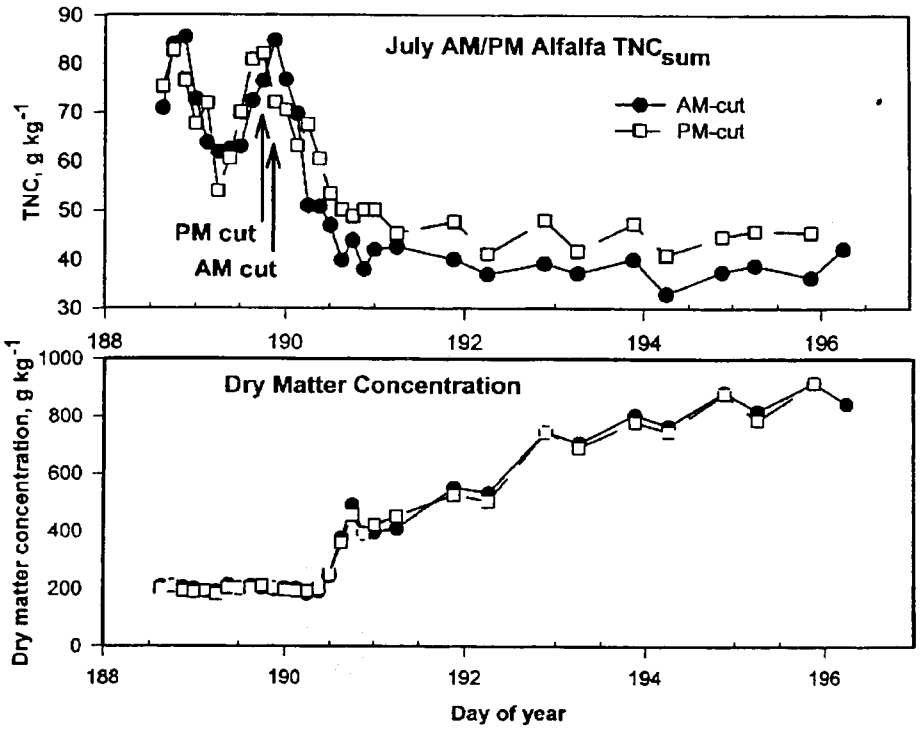


**Figure 1.** Daily variation in total nonstructural carbohydrate concentration and dry matter concentration and effects of PM- versus AM- cutting. The study was conducted near Kimberly, ID during July 1997.

The dry matter concentration, the reciprocal of moisture percentage, was not significantly affected by whether the alfalfa was cut in the PM or AM (Figure 1). Hay should not be cut with a heavy dew at any time of day. Producers east of the 100$^{th}$ meridian with only a 3-day drying period need to consider tedding or the advantage of cutting earlier in the day to maximize drying rate. In those conditions, drying forage to limit plant or microbial respiration may be more important for conserving TNC than PM-cutting.

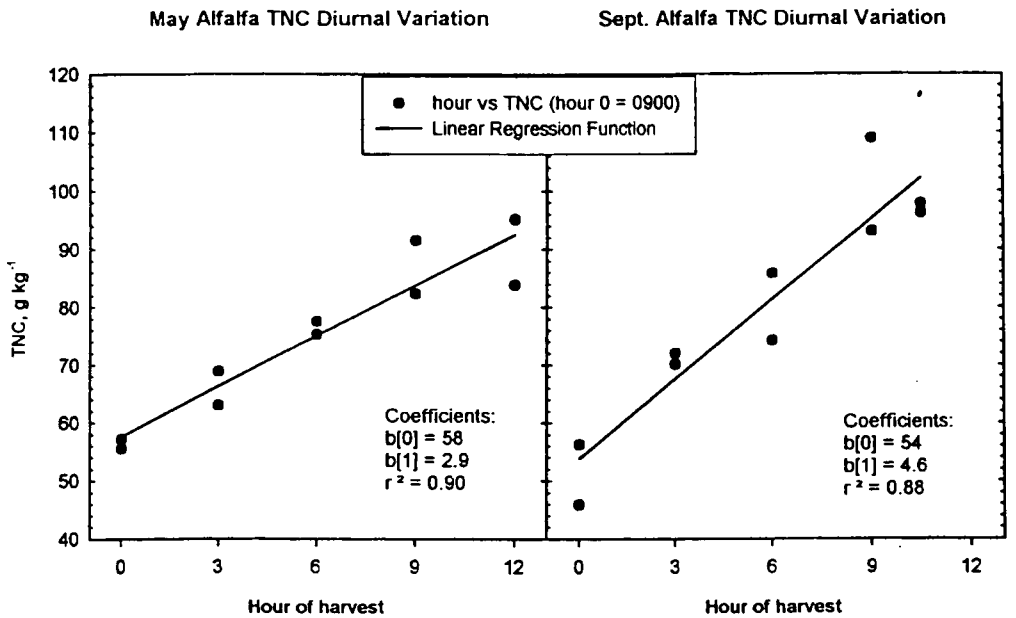


**Figure 2.** Daily variation of total nonstructural carbohydrates (TNC) in 'WL 322HQ' alfalfa at Kimberly, ID in May and September of 1997. The curves are sinusoidal over a 24-h period, but linear between 0900 (harvest hour = 0) and about 1800 MDT.

From these results, we conclude that TNC concentrations in alfalfa can increase linearly during the day. To maximize the TNC concentration in alfalfa, center your cutting time on 6 pm. If you need to cut 12 hours per day, begin cutting at noon and quit at midnight to capture the most TNC in the hay. If you have to cut in the morning, cut a field that is already too mature for dairy quality hay and keep the lots separate. Many dairymen are aware of the better quality of PM-cut hay and hay producers should market this advantage. The increased forage quality can be determined experimentally because of replications, but perhaps not commercially, as a 1% reduction in ADF. A direct measure of TNC by NIRS or the wet chemistry procedure of Smith (1969) will be more accurate than a computed value of non-fibrous carbohydrates calculated as 100 - (% NDF + %CP + %fat + % ash).

## Review of AM-PM Cut Hay Preference Study

Daily cycling of TNC in alfalfa has been reported (Lechtenburg et al., 1971; Putnam et al. 1998), however, the application of this knowledge to producing higher forage quality and improved palatability is largely ignored. Beef cattle, sheep, and goats all preferred tall fescue and alfalfa hays harvested in the afternoon over hays harvested in the morning. Preferences and intakes were associated with the level of soluble carbohydrates in the forage. Beef steers consumed more PM-cut than AM-cut alfalfa (Table 1) in the experiment by Fisher et al. (2002). Dry matter intake was negatively correlated with lignin and nitrate-N ($R^2 > 0.99$). Cellulose had a relatively small positive coefficient and starch had a relatively large positive coefficient. Digestibility analysis for this study has been submitted for publication in J. Animal Science (Burns et al. xxxx) Thus we come back to Van Soest's interpretation and the

"post-ingestive feedback" hypothesis suggested by Provenza (1995). Lignin is a difficult wet lab procedure in terms of repeatability and NIRS is not very accurate.

Although dry matter intake is negatively related to NDF and positively related to TNC, note the large difference in DMI for the PM-8 July and AM-9 July cut hays versus hays cut in PM-14 August and AM-15 August. Intake is about twice that for the July 8-9 cuts as for the August 14-15 cuts, but ADF and NDF are about the same. Our hypothesis is that higher air temperatures are associated with faster growth rates of alfalfa and higher lignification than alfalfa grown in cooler temperatures. Higher elevation hay is grown under high solar radiation--good for photosynthesis--but cooler temperatures--hence less plant respiration which conserves TNC. Idaho extension is currently building a database of alfalfa yield and quality from alfalfa grown at a series of elevations up the Snake River Plain. This information will be correlated to weather data collected from automated weather stations nearby.

**Table 1.** Intake by beef steers and composition of alfalfa hays as affected by cutting date and time of day (Source: Fisher et al. 2002). Steers were fed all combinations in pairs as a portion of their diet.

| Hay | ADF | NDF | TNC | Intake |
|---|---|---|---|---|
| | --- | % | --- | g/meal |
| **PM-8 July** | **31.1** | **40.7** | **4.29** | **1022** |
| AM-9 July | 32.8 | 42.7 | 3.49 | 842 |
| **PM-14 Aug** | **32.0** | **41.9** | **5.16** | **619** |
| AM-15 Aug | 32.5 | 42.0 | 3.97 | 324 |
| **PM-22 Sept** | **27.9** | **36.6** | **6.55** | **1320** |
| AM-23 Sept | 28.5 | 37.2 | 5.46 | 1107 |
| | | | | |
| **PM mean** | **30.3** | **39.7** | **5.33** | **987** |
| AM mean | 31.2 | 40.6 | 4.31 | 758 |

### *Conclusions*

- There is daily cycling in forage quality and this is important to consider when testing forage or testing animal preference or intake of forage.
- The PM-cut hay quality is greater than AM-cut.
- We estimate 136 (first cutting) and 81 lbs TNC/ac (fourth cutting) increase by PM- versus AM-cutting.
- Ruminants prefer and eat more PM- than AM-cut hays.
- A decrease of 1% ADF is worth @ $10 to 15/ton at today's prices for premium alfalfa hay.

- Although NDF is related to intake and ADF is related to digestibility, neither is a good indicator of animal intake or production between hays of different cutting season. More accurate forage tests are needed.
- Determination of NFC, TNC, or dNDF in addition to common lab tests for ADF, NDF, RFV, and CP should improve prediction of DMI and animal production.
- Use of newer summative equations should be about 90% accurate versus 70% for old equations.

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