

Increasing Non-Structural Carbohydrates in Forages

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Non-structural carbohydrates are an important source of readily fermentable energy available to rumen microbes. Limited concentrations of readily available energy in forages combined with fast and intensive protein degradation contribute to poor nitrogen use efficiency by dairy cows and other ruminants. Non-structural carbohydrates are also the main source of fermentable substrates during ensiling. Increasing non-structural carbohydrates in forages has been shown to improve feed intake, milk yield and nitrogen use efficiency.

Non-structural carbohydrates include water soluble carbohydrates (glucose, fructose, sucrose, fructans in grasses and pinitol in legumes) and starch. Factors that affect plant growth and metabolism, such as climate, harvest management and fertilization, are likely to also affect forage non-structural carbohydrate concentration. Several strategies exist to increase the concentration of non-structural carbohydrates.

Morning vs. afternoon cutting

Plant carbohydrate concentration in herbage increases during the day when carbohydrate synthesis through

photosynthesis exceeds utilization. This suggests the possibility of cutting at a time during the day when non-structural carbohydrate concentration is the highest. Studies conducted in different areas of North America and with different forage species have shown that cutting later in the day results in forages with greater non-structural carbohydrate concentrations, particularly on a sunny day. This diurnal increase in non-structural carbohydrate concentration is up to 60 g/kg of dry matter (6% of dry matter) and comprises mostly starch in legumes and sucrose in grasses. Greatest non-structural carbohydrate concentrations are usually reached 11–13 h after sunrise (Fig. 1) in both grasses and legumes and in both spring and summer regrowth. Hence, grass and legume species are likely to have a greater non-structural carbohydrate concentration when cut in the afternoon compared to the morning. This diurnal increase has been observed in most forage species although the extent of the increase might vary with species (Fig. 2). Greater non-structural carbohydrate concentrations with PM-cut forages are observed through the growing season in spring, summer and autumn growth cycles. The benefits of PM-cut forages also include other nutritive attributes such as lower

concentrations of acid detergent fiber (ADF) and neutral detergent fiber (NDF) and greater dry matter digestibility.

Species

Producers in many regions have access to several forage species and mixtures but there is little information on which species or combination of species has greater non-structural carbohydrate concentrations. Legumes are reputed to have lower non-structural carbohydrate concentrations than grasses but a study conducted in eastern Canada showed that alfalfa had similar non-structural carbohydrate concentrations to timothy, one of the main grass species in this region (Fig. 2). The high non-structural carbohydrate concentration in forage legumes is due in part to greater amount of starch in legumes than in grasses; starch is used as temporary carbohydrate storage in forage legumes. Pinitol, a carbohydrate found in legume species but not in grasses, also contributed to the increase in non-structural carbohydrate concentration. In contrast, fructans, a reserve carbohydrate in grasses, do not seem to play a significant role in increasing forage non-structural carbohydrate concentration.

Few studies have compared non-structural carbohydrate concentration in forage species. Among legumes, there is information that red clover has a greater non-structural carbohydrate concentration than alfalfa. Among forage grasses, tall fescue has the greatest while reed canarygrass had the lowest non-structural carbohydrate concentration. Legume or grass species with a high non-structural carbohydrate concentration tend to also have lower concentrations of ADF and NDF, resulting in a greater *in vitro* digestibility of dry matter. Species selection is one of the tools that can be used to increase forage non-structural carbohydrate concentration but there is currently insufficient information for recommendations.

Cultivars with improved non-structural carbohydrate concentration

Forage non-structural carbohydrate concentration can be improved by genetic selection but the potential for improvement of most forage species is not known. In the United Kingdom, perennial ryegrass varieties with an increased sugar concentration (up to 80 g/kg of dry matter or 8%) were successfully developed to improve herbage intake and milk production. However, there are few reports on genetic variability and the possibility of genetic improvement for sugar concentration for most forage species.

Two examples of studies with alfalfa suggest that improving the concentration of available carbohydrates by breeding should be possible. Over the last five years, the possibility of increasing the non-structural carbohydrate (soluble sugars and starch) concentration of alfalfa via genetic selection was investigated in eastern Canada. Two

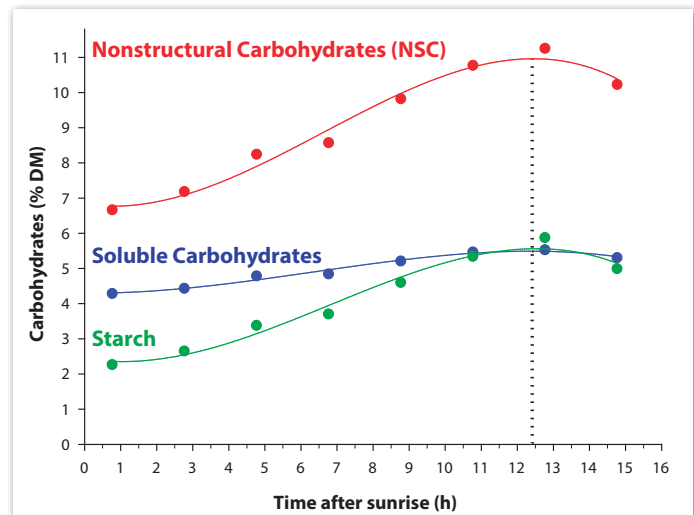


Figure 1. Diurnal variations in alfalfa concentrations of starch and non-structural carbohydrates (NSC) (NSC = starch + soluble carbohydrates; soluble carbohydrates = sucrose + glucose + fructose + pinitol + maltose) in a summer regrowth at Lévis, Quebec, Canada. Dotted line represents h after sunrise when the NSC concentration reached its maximum value. Adapted from Morin et al. (2011).

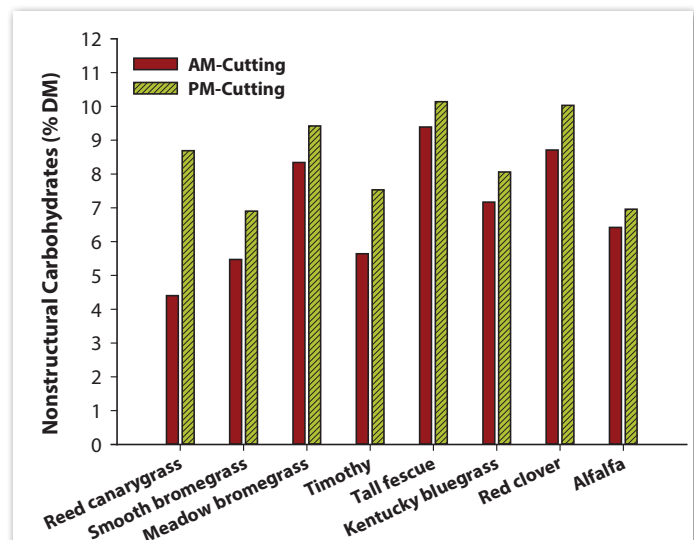


Figure 2. Concentrations of non-structural carbohydrates [estimated by the sum of sucrose, glucose, fructose, pinitol (legumes), low and high degree of polymerization fructans (grasses), and starch] in spring growth of six grasses and two legumes cut in the morning (8–10 AM) or the afternoon (3–4:15PM). Adapted from Pelletier et al. (2010).

populations were obtained by inter-crossing 10 genotypes selected for high (NSC+) or low (NSC-) non-structural carbohydrate concentrations from 500 genotypes of the well-adapted cultivar AC Caribou. The populations were compared in a field experiment established in 2006. The NSC+ population had a greater non-structural carbohydrate concentration (10 and 5 g/kg of dry matter, or 1 and 0.5%, in 2007 and 2008, respectively) than the NSC- population. In both years, the NSC+ and NSC- populations did not differ for CP, ADF and NDF concentrations, *in*

vitro total digestibility, NDF digestibility or yield.

An alternative approach to increase non-structural carbohydrate concentration is to increase the concentration of pectins. Pectins are completely digestible carbohydrates. Pectin concentration in alfalfa can be estimated from the neutral detergent-soluble fibre (NDSF) concentration, which can be predicted by near infrared reflectance spectroscopy. Genetic selection for NDSF concentration in alfalfa conducted in New York was effective in increasing or decreasing NDSF, with corresponding effect on herbage digestibility.

Stages of development at harvest

Variations of non-structural carbohydrate concentration with stage of development are inconsistent. For timothy, lower concentrations of water-soluble carbohydrates were observed in later harvest in Sweden, Finland and eastern Canada but results were variable in Norway. Harvesting timothy at the anthesis stage resulted in higher non-structural carbohydrate concentration than earlier harvests but this practice is not recommended because of high forage fibre concentration and low digestibility. This shows that the relationship between non-structural carbohydrate concentration and stage of development is not definitive. This is due, in part, to the confounding effects of stage of development and climatic conditions (solar radiation and temperature) especially on the day of harvest.

In the fall, however, delaying harvest can result in significant increases in water-soluble carbohydrates because of decreasing air temperatures. Cool-season grasses generally have a higher concentration of non-structural carbohydrates when grown at cool temperatures (5-10°C) than at warm temperatures (15-25°C). At temperatures below the optimums for growth, carbohydrates accumulate because photosynthesis is usually less sensitive to low temperatures than growth (i.e. photosynthesis continues at the same rate while growth slows).

Spring, summer and autumn growth

The effect of the growing season on non-structural carbohydrate concentration is not clear. There are reported increases

(smooth brome grass, timothy, alfalfa), decreases (meadow brome grass, tall fescue, Kentucky bluegrass), or no change (reed canarygrass, red clover) in non-structural carbohydrate concentration with the growing season. Seasonal variations in concentrations of both non-structural carbohydrate and structural carbohydrate are reported in several legume and grass species, but peaks in carbohydrate concentrations occur at different times of the year depending on, among other factors, forage species and location. The effect of temperature, photoperiod and other factors affecting non-structural carbohydrates vary among growth periods. Forages harvested in late fall (e.g. October in eastern Canada) are likely to have much greater non-structural carbohydrate concentrations than those harvested in summer or early fall.

Nitrogen fertilization and grass non-structural carbohydrates

Nitrogen fertilization can significantly affect forage grass composition. Lowering N fertilization, for example, has been shown to increase non-structural carbohydrates and reduce CP concentrations of several grass species (timothy, orchardgrass, tall fescue) which can lower N losses and improve the N use efficiency of cattle. However, lower N fertilization may also reduce grass yield and insufficient protein in the diet adversely affects animal performance. Therefore, the challenge is to manage N fertilization to increase forage non-structural carbohydrate concentration and improve the N use efficiency of cattle without affecting either forage yield or animal production.

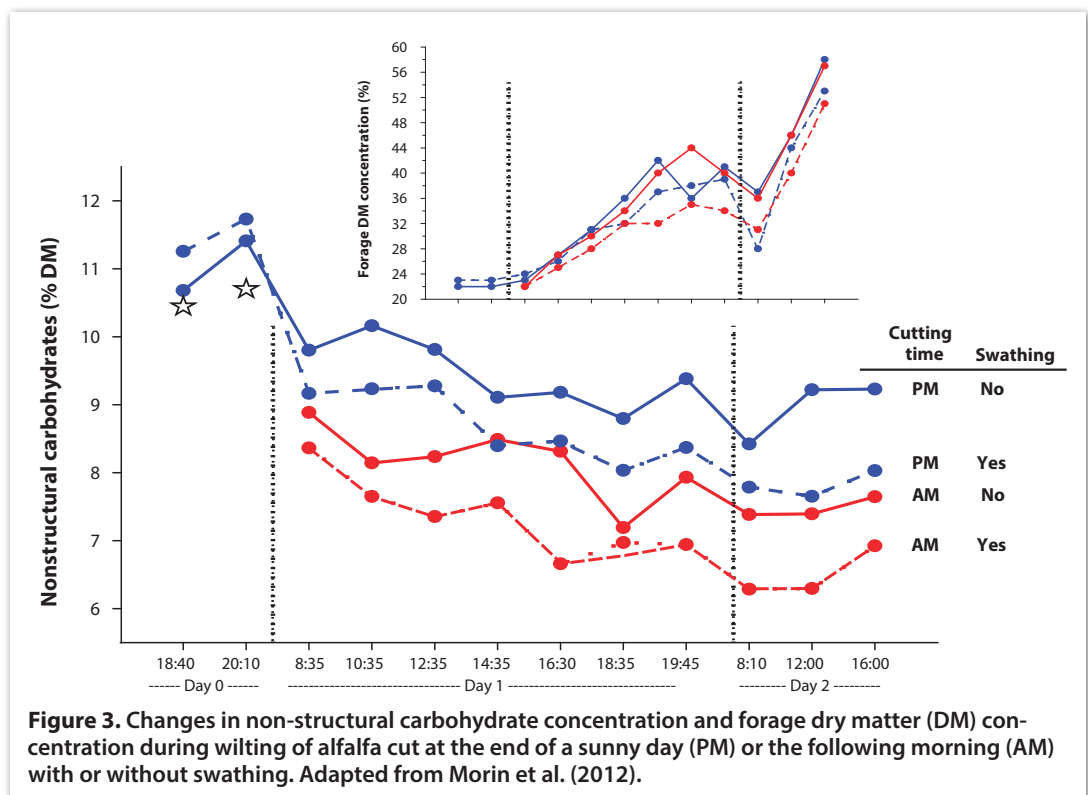


Figure 3. Changes in non-structural carbohydrate concentration and forage dry matter (DM) concentration during wilting of alfalfa cut at the end of a sunny day (PM) or the following morning (AM) with or without swathing. Adapted from Morin et al. (2012).

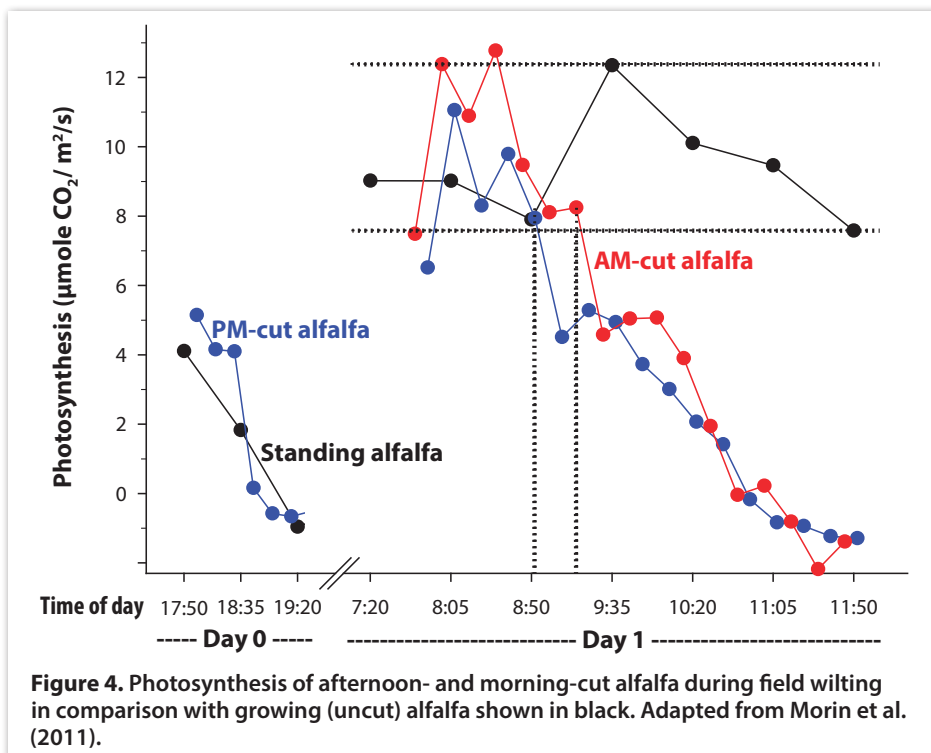


Figure 4. Photosynthesis of afternoon- and morning-cut alfalfa during field wilting in comparison with growing (uncut) alfalfa shown in black. Adapted from Morin et al. (2011).

Variation of alfalfa non-structural carbohydrate concentration during wilting

Plant cells stay alive after cutting and continue to use non-structural carbohydrate for respiration until they die. Alfalfa non-structural carbohydrate concentration progressively decreases at a rate ranging from 0.2 to 3.5 g/kg DM/h (0.02–0.35% per h) during the first day of wilting (Fig. 3). This rate of decrease in non-structural carbohydrate concentration is not affected by the time of cutting (afternoon vs. morning). Consequently, afternoon-cut alfalfa still has greater non-structural carbohydrate concentrations than morning-cut alfalfa at the end of the wilting period provided that drying conditions are optimal.


It is often thought that afternoon-cut alfalfa will lose a significant proportion of its non-structural carbohydrates during the night, hence losing its advantage over morning-cut alfalfa. However, recent research has shown that nighttime non-structural carbohydrate losses in alfalfa cut in late afternoon are minimal and that these losses are more than compensated for by early morning photosynthesis of the cut herbage. Photosynthesis of cut alfalfa continues for up to 3 h in the morning until dry matter content reaches around 350 g DM/kg (35%) (Fig. 4). Afternoon-cut alfalfa, having undergone no wilting during the night, can start to photosynthesize again the following morning (day 1) at the same rate as the morning-cut alfalfa and the uncut alfalfa.

Variation of non-structural carbohydrate concentration during silage fermentation

Soluble carbohydrates, such as glucose, fructose and sucrose are quantitatively the most important substrates

for fermentation during ensiling. Consequently, concentration of non-structural carbohydrate decreases during fermentation and the extent of this decreased concentration may vary with the silage DM concentration. Because of this decrease in non-structural carbohydrate concentration during fermentation, forages with high non-structural carbohydrate concentration might lose their advantage during the fermentation process. Nonetheless, Canadian studies have shown that haylage from afternoon-cut alfalfa and timothy had greater non-structural carbohydrate concentrations than haylage made from morning-cut forage.

High non-structural carbohydrate silage in 24 hours

Wilting conditions affect forage non-structural carbohydrate concentrations. Fast drying results in less respiration time and consequently less use of non-structural carbohydrates. Under poor drying conditions, drying non-swathed alfalfa reduces wilting time by up to 9 h compared to swathed alfalfa, resulting in greater non-structural carbohydrate concentrations. Therefore, combining late afternoon-cutting with wilting in wide swaths can be used to significantly increase non-structural carbohydrate concentrations of wilted alfalfa forage (Fig. 3). When wilting conditions provide fast drying and two consecutive sunny days are forecasted, producers could cut alfalfa in late afternoon in wide swaths to produce wilted alfalfa forage with high non-structural carbohydrate concentrations in less than 24 h. 

References available online at www.farmwest.com

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