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Nonstructural carbohydrates: how to increase their concentration in forages and how does it affect animal performance?

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ABSTRACT. Forages have a low fermentable energy content. To use the non-protein nitrogen in forages efficiently, microbes in the rumen need a readily available energy source. Increasing the energy content in forages has been the focus of our research. Our objectives were to 1) Develop crop management practices that promote energy accumulation in forages; 2) Assess the impact of high-sugar-content forage on the in vitro synthesis of microbial proteins, and on ingestion, nitrogen utilization efficiency, and dairy cow performance. The principal findings of this research are presented. We demonstrated that the choice of forage species and late-afternoon mowing into wide swaths are potential ways to increase the sugar content in forages. This increase in the sugar content of forages results in an increase in the synthesis of microbial protein measured in vitro and, in most cases, results in an increase in ruminal propionate. High sugar content in forage is also associated with an increase as high as 5% in feed intake and milk production when cows are fed mainly higher-sugar-content forages.

Key words: forages, soluble carbohydrates, late-afternoon mowing, sugar contens

Carbohidratos no estructurales: cómo aumentar su concentración en los forrajes y cómo afecta el rendimiento de los animales?

RESUMEN. Los forrajes tienen un bajo contenido de energía fermentable. Para utilizar el nitrógeno no proteico en los forrajes de manera eficiente, los microbios en el rumen necesitan una fuente de energía fácilmente disponible. El aumento del contenido energético de los forrajes ha sido el foco de nuestra investigación. Nuestros objetivos fueron: 1) Desarrollar prácticas de manejo del cultivo que promueven la acumulación de energía en los forrajes, 2) Evaluar el impacto de los altos contenido de azúcar en el forraje en la síntesis in vitro de proteínas microbianas, y en la ingestión, la eficiencia de la utilización de nitrógeno, el rendimiento de la vaca la ingestión. Los principales hallazgos de esta investigación se presentan. Hemos demostrado que la elección de las especies forrajeras y el corte hacia el final de la tarde en amplias franjas es una posible vía para aumentar el contenido de azúcar en los forrajes. Este aumento en el contenido de azúcar de los forrajes ha resultado en un aumento en la síntesis de proteína microbiana, medida in vitro y, en la mayoría de los casos, se traduce en un incremento de propionato ruminal. Alto contenido de azúcar en el forraje también se asocia con un aumento de hasta el 5% en el consumo de alimento y la producción de leche cuando las vacas se alimentan principalmente de forrajes con alto contenido de azúcar.

Palabras clave: forrajes, carbohidratos solubles, corte hacia el atardecer, contenido de azúcar

Introduction

The concentration of nonstructural carbohydrates (NSC) varies diurnally in forage because of the plants' potential to accumulate carbohydrates during the day. Thus, daytime cutting management (PM- vs. AM-cut) offers an alternative to increase NSC concentration of grasses and legumes. We hypothesized that feeding high NSC forage would improve N utilization, dry matter intake, and milk yield in dairy cows. Our objective was to increase the energy content of forages with the overall goal of

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improving dairy cow performances via increased dry matter intake and nitrogen use efficiency. Specific objectives were 1) to develop crop management practices that favour the accumulation of energy in forages; 2) to evaluate the impact of a forage rich in energy on *in vitro* dry matter digestibility and microbial protein synthesis, and on intake, N utilisation efficiency, and performances of dairy cows.

1) Development of crop management practices

First we studied the diurnal variations of NSC concentration and other nutritive value attributes in alfalfa and timothy to determine the best time during the day to cut forage for maximizing NSC concentration. We found that the greatest NSC concentrations were reached between 11 to 13 h after sunrise for alfalfa and timothy (Morin et al., 2011). Then, the NSC concentrations of several grass and legume species were compared. We also wanted to determine how variations of NSC concentration caused by time of cutting during the day differ among forage species and how these variations are related to other attributes of forage nutritive value. Six grass and two legume species were cut in the AM and PM, in the spring and summer regrowth of two harvest years. Red clover and tall fescue had the greatest NSC concentration [94.2 g kg^{-1} of dry matter (DM) across time of cutting and growth periods] whereas reed canarygrass had the lowest NSC concentration (65.5 g kg^{-1} DM). Concentration of NSC of all species increased with PM-cutting but the extent of this increase varied among forage species. This increase, averaged across growth periods, went from 13% in smooth bromegrass to 68% in reed canarygrass. Increased NSC concentration with PM-cutting resulted in significant but small decreases in N, ADF, and NDF concentrations and a small increase in IVTD (Pelletier et al., 2010). We concluded that both species selection and PM-cutting can be used to increase forage NSC concentration. Forage NSC concentration can also be improved by genetic selection. Thus, the objective of our third experiment was to determine the effect of selected populations of alfalfa for high(NSC+) and low(NSC-) concentrations of NSC, cut in the AM or the PM, on NSC concentration and other attributes of nutritive value. In the establishment and production years, NSC concentrations increased respectively by 13 and 6% with NSC+ compared to a control (NSC0) population and by 46 and 37% with PM- compared to AM-cutting. There was no interaction between populations and time of cutting. In general, PM-cutting decreased ADF, NDF, and CP concentrations, and increased IVTD and dNDF. The NSC+ and NSC- populations did not differ for CP, ADF, NDF, IVTD, and dNDF (Chouinard-Michaud *et al*., 2010). Alfalfa NSC concentration can be increased by cutting the forage in the PM and via genetic selection; this increase was more important with time of cutting than with selection. Additional cycles of selection may further increase NSC concentration and we are currently testing this hypothesis. As in the previous experiment, the increase in NSC concentration with PM-cutting was associated with a decrease in ADF and NDF concentrations, and an increase in IVTD and dNDF. In a subsequent trial changes in NSC concentration during wilting of PM- and AM-cut alfalfa were measured (Tremblay *et al*., 2010). At cutting, alfalfa NSC concentration was on average 24% greater in PM- than in AM-cut alfalfa. Concentration of NSC remained greater in PM- compared to AM-cut alfalfa throughout the wilting period. The rate of decrease in alfalfa NSC concentration during wilting was lower in summer and fall when drying conditions were superior. Wilting was effectively faster in summer and fall; at the end of the second day, forage DM concentration reached 26-34% in spring, 34-41% in summer, and 36-43% in fall. When wilting was fast, in summer and fall, alfalfa NSC concentrations were on average 8% greater with no swathing than with swathing after cutting. No swathing after cutting helps preserving NSC concentration in alfalfa forage, especially when conditions allow fast wilting. Cutting alfalfa in the PM, without swathing, maximizes NSC concentration in wilted forage.

2) Impact of a forage rich in energy on *in vitro* dry matter digestibility and microbial protein synthesis, and on performances of dairy cows.

First, samples of high- (179 g kg^{-1} DM) and low- (74 g kg^{-1} DM) NSC alfalfa were respectively allocated to six separate dual flow fermenters (Berthiaume et al., 2010). High- versus low-NSC concentration in alfalfa significantly enhanced the apparent digestibility of OM (59.1 vs. 54.4%), DM (60.0 vs. 54.3%), and the true digestibility of DM (74.1 vs. 64.7%). Increasing NSC concentration in alfalfa significantly decreased ruminal pH (6.85 vs. 7.08) and NH_3-N concentration (26.0 vs. 33.6 mg/dL) and increased total VFA concentration (94.9 vs. 83.0 m*M*). Molar proportions of acetate, isobutyrate, and isovalerate significantly decreased, whereas molar proportions of propionate and butyrate significantly increased with high-NSC alfalfa, resulting in a more glucogenic fermentation. More importantly, microbial-N flow (263 vs. 230 mg/day) and bacterial-N efficiency (41.1 vs. 29.6% of available N), measured using ^{15}N as a microbial marker, both significantly increased with the high-NSC alfalfa. We concluded that increasing the

concentration of NSC in alfalfa promoted a glucogenic fermentation and enhanced microbial-N synthesis in the rumen. Our *in vitro* studies needed to be confirmed *in vivo* with dairy cows fed at greater feeding and passage rates. We conducted 3 *in vivo* studies with cows in early, mid, and late lactation (Brito et al., 2008; 2009). Our most recent study examined the effects of feeding high-NSC alfalfa on the performance of early-lactation cows fed a 41% concentrate diet. Dry matter intake and milk yield did not differ across treatments. Whereas, 4% fat corrected milk (FCM) was lower when cows were fed the high- vs. low-NSC treatment due to reduced milk fat concentration with the former diet. Reduced milk urea nitrogen with the high- vs. low-NSC treatment suggests better N utilization. Overall, high-NSC alfalfa had no effects on performance of early-lactation cows fed a 41% concentrate diet. This was likely due to the lack of a biologically significant difference in the NSC concentration of the two diets. We also examined the effects of feeding a high-NSC timothy based TMR on the performance of mid-lactation cows. Dry matter intake and yields of milk components (fat, protein, lactose) were all higher in cows fed the High- vs. the Low-NSC diet. Compared with the Low-NSC diet, the High-NSC diet increased FCM yield. Overall, the high-NSC TMR enhanced performance of mid-lactation cows fed a 35% concentrate diet. Finally, 16 late-lactating dairy cows were used to investigate the effects of alfalfa daytime cutting management on ruminal metabolism, nutrient digestibility, N balance, and milk yield. A significant time of sampling by treatment interaction was observed for rumen pH. Rumen pH was significantly higher comparing PM- vs. AM-cut alfalfa at 2, 3, 4, 6, and 8 h post-feeding possibly because the rumen molar proportion of acetate and total VFA concentration were lower when cows received the PM- rather than the AM-cut alfalfa treatment. We also observed a significant decline in the acetate:propionate ratio in cows fed PM-cut alfalfa. Concentrations of rumen ammonia did not differ between treatments. Eight ruminally cannulated cows that were part of the lactation trial were also used to investigate the effects of alfalfa cutting time on digestibility and omasal flow of nutrients. Intakes of DM and OM were both greater when feeding PM- rather than AM-cut alfalfa. Yields of milk and milk components were also significantly higher when cows were fed PM- vs. AM-cut alfalfa. Digestible OM intake was 0.8 kg/d higher when feeding PM- rather than AM-cut alfalfa. Omasal flow of OM tended to be higher when feeding PM- rather than AM-cut alfalfa to late-lactation dairy cows whereas OM apparently digested in the rumen and postrumen, and truly digested in the rumen did not differ between treatments. However, apparent total tract digestibility of OM was 0.8 kg/d greater with feeding PM- instead of AM-cut alfalfa. Therefore, increased milk production of late-lactation cows fed PM-cut alfalfa could be explained by the enhanced intake, omasal flow, and total tract digestibility of OM. Intakes, omasal flows, and apparent digestibilities of N, NDF and ADF in the rumen and postrumen did not differ when cows were fed PM- or AM-cut alfalfa baleage. However, N truly digested in the rumen, expressed as a % of N intake, was higher when cows were fed PM- (79%) vs. AM-cut alfalfa (74%), thus suggesting that enhanced availability of ruminally fermentable energy increased degradability of alfalfa protein. Omasal flow of total N, ammonia-N and NAN, expressed as g/d, did not differ when cows were fed PM- or AM-cut alfalfa. Omasal flow of total bacterial NAN (fluid-associated bacteria NAN plus particle-associated bacteria NAN) increased by 7% when cows were fed PM- vs. AM-cut alfalfa. Ruminal outflow of particle-associated bacteria NAN was 16 g/d greater when late-lactation cows were fed PM- vs. AM-cut alfalfa. Greater intakes of DM and OM when feeding alfalfa cut in the PM might explain the observed increase in the omasal flow of total bacterial NAN considering that OM truly digested in the rumen did not differ between treatments. Efficiency of N use, expressed in g of bacterial NAN/g of N intake, was greater when cows were fed PM- rather than AM-cut alfalfa baleage, which is in line with the significant increase in milk N efficiency observed.

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