# Forage Sources in Dairy Rations

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## INTRODUCTION

Forages account for a large portion of ruminant diets and their particular fiber fractions play a major role in feed utilization. Prior to being included in a dairy cow diet, both individually or in combination, the affects of various forage species on feed intakes and performance should be quite predictable. This would seem especially true if detailed quality analysis were predetermined, using current feed analytical methodology. Yet, the total comprehension of diet/forage interaction remains quite challenging for most applied, ruminant nutritionists. It is still exceedingly difficult to chemically fractionate, individual fiber sources into specific carbohydrate (**CHO**) components (inexpensively with speed and accuracy) in the lab; and even more so to realize their digestibility and nutrient availability when fed with an assortment of CHO fractions in a complex diet. With dynamic ratios of simple/complex CHO fractions, along with defined proportions of other essential nutrient fractions, the extent and type of feed processing, the amount of dry matter intake (**DMI**), and the rate of passage; the rumen environment is under constant flux. Furthermore, in-field variation based on field/plant genetic source mingling, harvest techniques, storage practices, and feeding accuracy, presents additional dimensions to the efforts of precision ration formulation.

The focus of this presentation is neither to describe nor compare complex, analytical laboratory techniques used to quantify forages into individual components of plant cell and cell walls. Rather, it is intended to review plant fiber fraction results from common forage testing and outline their usefulness when making forage substitutions in ruminant diets.

## MATCHING FORAGE WITH RUMINANT NEEDS

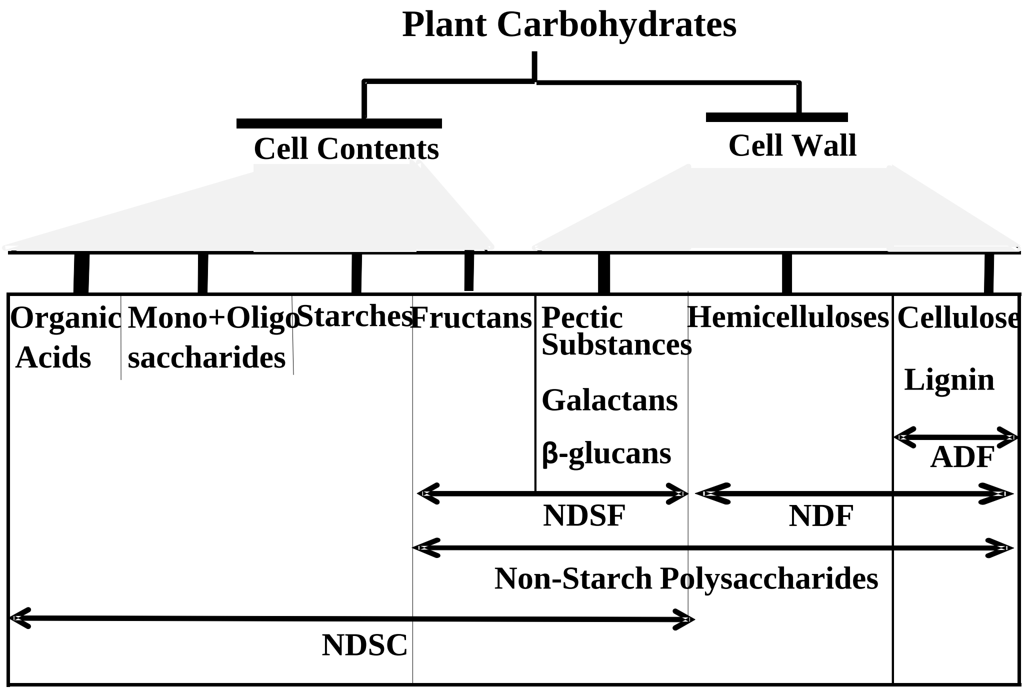
Forages are readily available and are a major source of organic material. Ruminants have taken advantage of this abundance as a nutrient supply by developing a complex, symbiotic relationship with microorganisms. Based on when they are consumed, the growth, development, and maturity of specific forage sources can be fundamentally important in matching the different nutrient schemes of animal production (growth, pregnancy, production, maintenance). From the time a plant seedling emerges to when it reaches chemical maturity, the nutrient levels and availability change in a wave-like motion. The chemical composition and feed value increase to a particular point during the growth phase before a gradual dilution begins. As a plant ages, the cell wall (fiber) continues to develop providing both structure, support, and an external defense mechanism. Depending on plant species, concentrations of particular nutrient components differ as well.

In animal husbandry, emphasis on nutritional requirements for different production levels in dairy animals is well established (NRC, 2001). Ruminant animal's nutrient demands are not constant at a given level or during the duration of a product phase (i.e., protein requirements for early vs. late gestation; early vs. late lactation). Matching forages to closely meet specific animal production levels, based on nutrient densities and availability, merits little explanation. Early animal scientists' recognized the disparity between forage quality and animal performance and began their investigations to determine why. Progress was initiated with simple laboratory techniques to isolate plant fiber fraction by the middle of the 19$^{th}$ century (Henneberg and Stohmann, 1859). Techniques for feedstuff analysis have since developed further to identify the primary components of forages (cell wall/structural and cell contents/non-structural), in addition to defining their individual nutrient composition (Moore and Hatfield, 1994; Van Soest, 1994; Ralph, 2003.

## PLANT COMPOSITION

In ruminant diets, plant carbohydrates constitute the majority of the energy provided for milk production. The general term *fiber* is used to define the complex carbohydrates of the plant cell wall. Fiber is the component of plant-derived feedstuffs composed primarily of β-1-4 linked polysaccharides, a bond that cannot be digested by mammalian enzyme systems (Moore and Hatfield, 1994).

**Figure 1.** Categorization of plant carbohydrate fractions into 2 major categories and subcategories. The NDSC contain the carbohydrates listed and others of the appropriate solubility. ADF = acid detergent fiber, Glucans = glucans, mono- + oligosaccharides = "sugars", NDF = neutral detergent fiber, NDSC = neutral detergent-soluble carbohydrates, NDSF = neutral detergent-soluble fiber (Hall 2000).




Carbohydrates are categorized as either structural (cell wall) or non-structural cell contents (**NSC**). These two categories are separated further to their specific fractions shown in Figure 1 (Hall, 2000). The principle factor that determines forage quality is plant genetics, followed by agronomic conditions, maturity, and storage.

## Cell Walls

In forages, there is a negative relationship between fiber concentration and quality. Higher fiber concentrations equate to lower consumption rates, reduced nutrient concentration, and depressed digestibility. Along with plant growth and maturity comes height and vulnerability to lodging. To remain standing, structural properties of the cell wall slowly increase, causing a marked decline in nutritive value. The expression "plant cells did not evolve to serve as a feed for ruminant animals" (Jung, 1997) carries great meaning. With exception of particular mutant varieties of plants (BMR genes), the ratio of leaves to stems decreases in aging plants followed by an increase in structural fiber concentration. Forages with greater fiber content contain less energy because of an elevated ratio of cell wall to cell contents. Cell wall is multifunctional in a living plant, and is composed of polysaccharides or complex carbohydrates (cellulose, hemicellulose, lignin, and pectin), the major source of dietary fiber. These cell wall components are the most resistant to microbial digestion, yet critical to optimal rumen function. Collectively, fiber is primarily plant cell walls and described as either acid detergent fiber (**ADF**) or neutral detergent fiber (**NDF**). The ADF provides an estimate of less digestible fraction of cellulose, lignin, lignified compounds, variable amounts of xylans, and insoluble ash. It does not represent the total fiber content, as hemicellulose fraction is not included (Van Soest, 1963a). Early equations predicting the energy content of feedstuffs used ADF as the major component. Acid detergent fiber is often considered as an indicator of fiber requirements for healthy rumen environment. It can be useful in comparing and estimating forage quality within forage species, because plant fiber is composed largely of cellulose and hemicellulose. Forage scientists (Weiss, 1998) suggest not using ADF to compare quality among different forage species. The amount of cellulose is relatively constant among forage species, but the amount of hemicellulose differs greatly between grasses and legumes. Because of the cellulose consistency among species, the grasses and legumes may have similar ADF values.

Neutral detergent fiber consists of ADF plus hemicellulose, and NDF values will generally be higher for grasses. The NDF provides a closer estimate of the plant's cell wall content (Van Soest, 1963b). Where ADF may represent the digestibility of forage or total digestible nutrients (**TDN**), NDF is an indicator of how much forage an animal will consume. Consumption in ruminants is a function of fiber content; and as fiber levels increase, intakes are depressed along with available energy. In dairy ration formulation, use of NDF in evaluating individual forage sources and predicting their energy content has great merit (Robinson and Putnam, 2007). Since structural fiber is the part digested slowest, it is NDF rather than ADF that is the best predictor of hay's energy content.

**Neutral Detergent Fiber Digestibility**

Initial observations by Van Soest (1965) showed the relationship between dry matter intake (**DMI**) and NDF. Subsequent researchers (Waldo, 1986; and Mertens, 1994) expressed the importance of NDF as a predictor in the filling effect and energy content in ruminant diets. Generally speaking, as the NDF content of a diet increases, DMI decreases due to rumen fill. The extent of this decrease is further complicated by the actual NDF composition, particle size, and concentration in the diet (Allen, 2000). As mentioned earlier, NDF is the cell wall material of the plant. It contains hemicellulose, cellulose, and lignin that vary individually in quantity depending upon source and maturity. Greater portions of one over another may not change the actual NDF amount in a sample, yet nutrient availability is influenced.

A means to improve the accuracy in predicting energy content of forages and other feed was proposed by Weiss (1998) using a summative equation. The equation included 4 principle components - crude protein (**CP**), fat, NFC and NDF, and corresponding digestibility coefficients for each nutrient. Lignin based calculations were used to determine the NDF digestibility (**NDFD**) coefficient and demanded arduous lab procedures. Lignin was chosen because; with increased lignification, plant species tend to become negatively associated with NDFD.

Today, feed NDFD values are commonly determined at commercial labs using *in vitro* techniques. Feed samples are artificially fermented and incubated in a simulated rumen environment using rumen fluid extracted from live animals, for specific time periods. The calculation is based on the sample amount of NDF prior to rumen incubation compared to the amount of NDF remaining after a designated amount of time, usually 30 to 48 hr. A question to ask is what time of incubation is most representative to the nutritionist, 30 or 48 hr? The 48 hr may be more repeatable, because of the longer incubation time. In reality, the difference between the 2 may be of little significance when considering the multitude of external influences on the energy status of ruminant animals (Hoffman et al., 2003).

Accuracy in predicting the energy content in corn silage can be increased by partitioning the single NSC component digestibility in 2 fractions, starch and non-starch (**NS**; Shaver et al., 2002). Starch in corn plants can approach up to one-third of the plant and its digestibility may vary in relationship to whole-plant maturity and processing. The concentration of NS component of corn silage is determined by subtracting the starch percentage from the NS. Regression equations run on data from literature predict total tract starch digestibility from whole-plant DM content for unprocessed and processed corn silage.

**Lignin**

Compensation for structural support in a maturing plant is strengthened further by formation of nature's plastic or cement, lignin. Lignin may have marginal nutritional value, yet exerts a major negative impact on digestibility and nutrient availability. Lignin is a chemical compound that fills in between cellulose, hemicellulose, and pectin components in the cell walls (Ralph, 2000). It forms covalent bonds, crosslinks various plant polysaccharides, and has multifunctional purposes. It plays a role in perfecting the vascular formation to efficiently conduct water, while simultaneously adding support by its increased concentration in the cell walls (Chaffey and Stokes, 2002). Lignin functionality is beneficial to the maturing plant; yet becomes a formidable barrier in rumen digestion because of its negative association with digestibility.

The biological functions of the cell wall have resulted in a structure formation that is variable among and between plant species and challenges the accuracy in predicting performance potential (Jung, 1997). High plant lignin levels present less of a problem with maintenance diets or for most replacement heifers, where feed nutrient intakes are controlled; but certainly can be problematic where optimum voluntary feed intakes and digestibility are critical to total energy intake.

**Cell Components**

The cell contents furnish the primary energy source. In dairy cows, milk production is a function of nutrient intake, mainly energy. The combination of total intake and nutrient density impacts milk flow.

The cell components are referred to as nonstructural or non-fiber carbohydrates (**NFC**). This includes the soluble fraction of the plant cells such as the organic acids, sugars, starch, and neutral detergent-soluble fiber (Hall and Van Horn, 2001)Figure 1). In a lactating cow diet, these carbohydrates are the primary sources of energy. Their individual concentrations can have a major impact on the end products of fermentation in the ruminal environment (Varga, 2003). In the rumen, microbes ferment the carbohydrates to volatile fatty acids (**VFA**). The primary VFA (acetic, propionic, and butyric) and various organic acids from fermented feeds are absorbed and utilized as energy sources for maintenance, milk and milk component synthesis, and tissue accretion. The rate and site of each carbohydrate fermentation or digestion vary. Sugars ferment quite rapidly in the rumen; whereas starch breakdown is variable and is affected by specific starch source, quantity, extent and type of processing, rumen environment (pH), and rate of passage. Neutral detergent-soluble (**NDS**) fiber includes pectin, beta-glucans, fructans, and various non-starch polysaccharides. Again, depending on the individual concentrations of these organic sources in a particular feed source, soluble fiber fermentation can be quite rapid or slow.

## BASAL FORAGE IN DAIRY DIETS

There are primarily 2 main plant family sources used in ruminant diets: *Graminaceae* and *Leguminous*, known as grasses and legumes, respectively. Grasses depend on structural matter in their leaves and leaf sheaths for standing tall; whereas legumes grow similar to trees and with leaves placed on the ends of outcropping branches (Van Soest, 1994). The difference in nutrient value between these two species is largely due to cell wall composition. Grasses tend to have lower concentrations of pectic substances compared to legumes and less protein deposited in the primary plant wall. Xylans are more abundant in grass walls than in legumes (Moore and Hatfield, 1994).

In the majority of dairy operations, alfalfa is considered the ideal forage. It contains all the attributes of desirable forage in diet formulation, both physically and nutritionally. Compared to other forages, high test alfalfa is low in NDF and high in protein, complementing the various concentrates and roughage in a ration. Quality alfalfa is palatable, nutrient rich, and promotes positive rumen function; thus is useful in optimizing DMI and milk production. The fundamental goal for any dairy producer is to achieve a positive return on investment. Although a particular feedstuff may be near perfect in a ration; diminishing returns based on cost, availability, and efficiency of nutrient conversion to milk remains critical (Etchebarne, 1995). In areas where dairy growth and large concentrations of animals are competing for a particular feed source, supply and demand may drive the cost of the particular ingredient above break-even. Failure to realize this event or refusal to remove or reduce an overpriced ingredient can have a major negative monetary impact on an operation. The extent of the impact generally goes unnoticed when other feedstuffs remain reasonably priced, or if milk prices are elevated. But when a marketing situation exists where the cost of production is high along with less than favorable milk prices, those who are responsible for optimizing production costs must step up and take action. To a certain extent, this situation already exists. Alfalfa production in the west is affected by water cost and availability, agronomic costs, transportation, weather, and competition from other crops. Strategies to reduce or remove this particular forage without experiencing major negative repercussions or consequences are entirely possible with today's nutritional knowledge base. Extensive efforts by research scientists have enabled commercial labs to quickly and accurately determine individual plant nutrient values and predict performance potentials.

## BY-PRODUCT FEED

By-product feedstuffs or non-forage fiber (**NFF**) are secondary products obtained during harvest or processing of a principal commodity and have value as an animal feed (Grasser et al., 1994). In most cases, the nutrient removed (starch, protein, fat) is designated for human consumption, leaving all the remaining components quite concentrated. Consequently, these products have similar ranges of NDF content as forages; therefore, their partial substitution for forage or grain in rumen diets is common. However, rates of NDF digestion in by-products differ among and within source largely due to their rate of passage compared to forage (Firkins, 1996). This accelerated passage rate results in reduced NDF digestion; thus lowering its rumen effectiveness up to a third of forage. In California, there are over 300 by-product commodities that represent a significant portion of the livestock feed (Bath et al., 1993). The inclusion of NFF in ruminant diets continue to gain importance, not only to minimize the negative impacts of plant food production systems on the environment; but in providing livestock and dairy cows with less expensive, alternative feed sources. One major nutritional concern with NFF is the lack of uniformity in chemical composition (DePeters et al., 2001). Realizing this variability in nutrient composition is important; management must subscribe to a program of frequent product sampling. Depending on the nutrient composition and uniformity, subsequent NFF designations can be based on feed cost and expected animal performance. Using current analytical procedures to define the fiber and non-fiber fractions as well as to predict nutrient values of the myriad NFF sources are crucial in diet formulation when using elevated levels of these products (Arana et al., 2001; Robinson, 2005). Common NFF include almond hulls, beet pulp, brewers grains, wet corn gluten, citrus pulp, whole cottonseed, cottonseed meal, rice bran, carrots, distillers grain, wheat millrun, and soy hulls.

## CONCLUSIONS

In an era of rising feed prices with emphasis on efficiency of agricultural production and resource use, the challenge of the modern dairy is to produce a high quality product while utilizing all available nutrient sources. Now, more than ever before, a dairy nutritionist will be forced to have a complete understanding of the various feed sources available to him and their underlying component fractions to build a nutrient rich and cost-effective ration. This short review has outlined a number of the key parameters that must be monitored to formulate cost-effective diets which meet the intake needs of high producing dairy cattle. With a strong understanding of the available nutrient sources and the dietary constraints for production animals in various stages of development, lactation, and environmental conditions; a high level of herd production, health, and profitability can be achieved.

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