WORKING WITH NON-NDF CARBOHYDRATES
With Manure Evaluation and Environmental Considerations

Mary Beth Hall
Department of Animal Sciences
University of Florida, Gainesville

The non-NDF carbohydrates (NFC) are an important source of energy in the rations of high producing cows, however, they vary in their effects on performance. Starch in particular has been associated both with the potential for high production as well as with problems related to ruminal acidosis (Sutton et al., 1987; Nocek, 1997) which leads to impaired health and production. Understanding how the array of NFC fit within the total ration picture, and how they differ in the nutrients they supply to the animal, will give a better sense of how we should use them in ration formulation.

Definitions

Although the terms NFC and NSC (nonstructural carbohydrates) have often been used interchangeably, they do not describe the same carbohydrates. NSC refers to sugars, starch and other cell contents. NFC refers to the calculated value (100 - crude protein - NDF - ether extract - ash; sometimes with the value of NDFCP added back) that is commonly used in ration formulation. Four general categories of NFC are organic acids, sugars (mono- and oligosaccharides), starch, and neutral detergent-soluble fiber (Figure 1).

Organic acids are not true carbohydrates, but are included in NFC for convenience. They include the fermentation acids found in silage (acetate, propionate, butyrate, lactate) and plant organic acids found in fresh forage and hay (malate, citrate, quinate, etc.). Those from fermented feeds, may be utilized by the animal, but do not support appreciable microbial growth in the rumen (Figure 2).

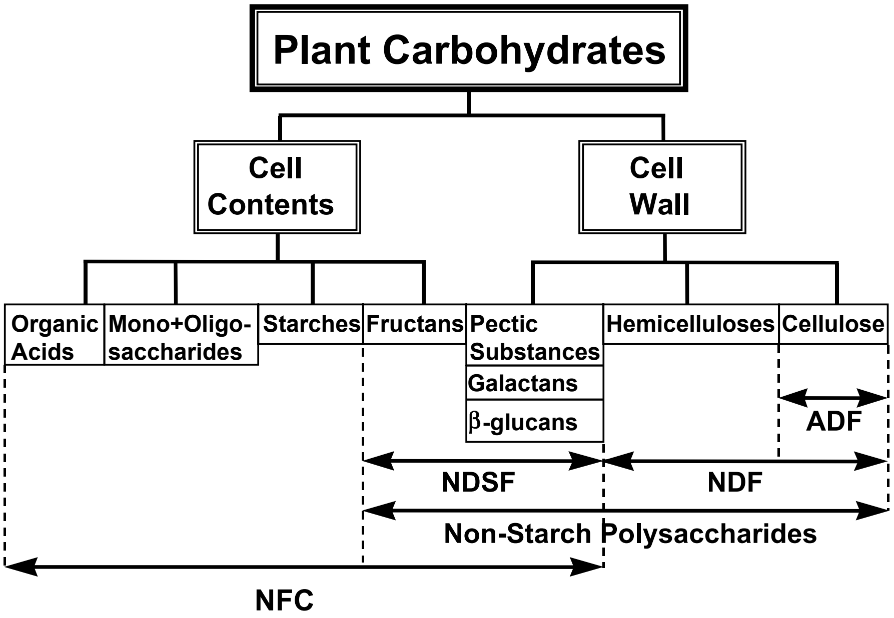
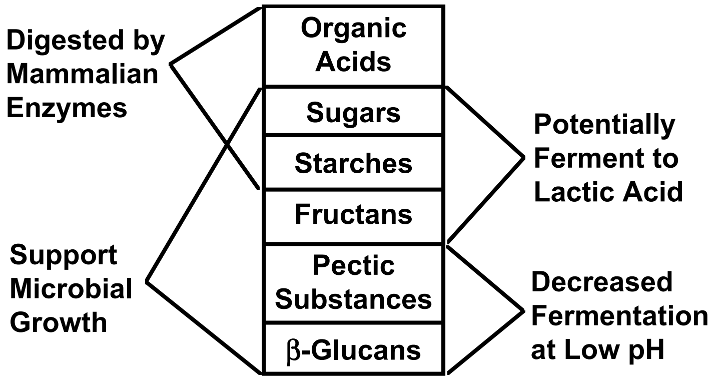


Figure 1. Plant carbohydrates. ADF = acid detergent fiber, NDF = neutral detergent fiber, NFC = non-NDF carbohydrates, NDSF = neutral detergent-soluble fiber, Sugars = mono- and oligo-saccharides. Lignin present in ADF and NDF is not included because it is not a carbohydrate.



<u>Typical Fermentation Rates</u>
Organic acids: 0-?%/h
Sugars: +/-80%/h (?)
Starch: variable, 4 - 30%/h
Soluble fiber: 20-40%/h
(exception: soyhulls at 4%/h)

Figure 2. Nutritional characteristics of neutral detergent-soluble carbohydrates.

"Sugars" include both monosaccharides (simple sugars) and oligosaccharides. The latter are short chains that are from 2 to ~20 sugar units long. The predominant sugars in plants are glucose, fructose, and the disaccharide, sucrose. Lactose is the disaccharide found in milk products. Sugars tend to ferment very rapidly, and may ferment to lactic acid. Fermentation of sugars tends to yield more butyrate than the other NFC, and levels of propionate similar to starch (Strobel and Russell, 1986). Except for some of the oligosaccharides, they may be digested by mammalian enzymes, and the resulting monosaccharides absorbed by the animal. Common sources of sugars include molasses, citrus pulp, almond hulls, some bakery waste, soybean meal, and fresh forages or hays. The carbohydrates in silages that analyze as sugars may be unfermented sugars, or short chains of other carbohydrates that were hydrolyzed by the acid conditions (Jones et al., 1992). The latter may have different fermentation characteristics than the naturally occurring sugars (W. Hoover, personal communication).

Starch is composed of alpha-linked chains of glucose that are stored in crystalline granules by plants. The alpha-linkages allow starch to be digested both by microbes and cow, but there is great variation in the rate of fermentation or digestion depending upon the processing, storage method, or plant source of the starch. Starch fermentations may yield lactic acid. Common sources of starch include small grains, corn and sorghum grains, silages and by-products, potatoes, and bakery waste.

Neutral detergent-soluble fiber includes pectic substances, (1->3)(1->4)-beta-glucans, fructans, and other non-starch polysaccharides not included in NDF. These carbohydrates cannot be digested by mammalian enzymes, and must be fermented by microbes to be digested. Soluble fiber tends to ferment very rapidly (20-40%/h), except for that in soyhulls (~4%/h). Pectins, which usually predominate in soluble fiber, tend to yield more acetate than the other NFC (Strobel and Russell, 1986). With the exception of fructans, soluble fiber fermentation yields little or no lactate, and its fermentation is reduced at more acidic pH in a fashion similar to the fermentation of NDF. Common sources of soluble fiber include legume forages, citrus pulp, beet pulp, soyhulls, and soybean meal.

Table 1. Lactation studies comparing starch and soluble fiber sources.

	Mansfield et al., 1994		Solomon et al., 2000		Leiva et al., 2000	
	Corn	Beet Pulp	Corn	Citrus	Hominy	Citrus
DM Intake, lb	47.4*	44.8*	46.1*	44.8*	47.2	46.1
Milk, lb	71.0	70.3	78.3	76.3	72.3	69.0
Fat %	3.64*	3.82*	3.33	3.38	3.43	3.54
Fat lb	2.60	2.67	2.60	2.56	2.47	2.45
Protein %	3.01*	2.90*	3.00*	2.93*	2.83*	2.71*
Protein, lb	2.14*	2.03*	2.31†	2.23†	2.05†	1.87†
Milk N/Intake N	0.24x	0.25x	0.31x	0.29x	0.24†	0.22†

* $P < 0.05$, † $P < 0.15$.
x = calculated from data in paper.

Although the types of organic acids produced from their fermentations differ, NFC have been considered to give similar yields of microbial protein when pH is relatively neutral and fermentation rates are similar.

Animal Performance

With the exception of starch, comparatively few research trials have evaluated the impact of different NFC on the performance of lactating cows. Most research evaluated feedstuffs rather than carbohydrate types, owing to a lack of methods with which to measure NFC fractions. Nonetheless, several studies suggest that the profile of NFC in the diet can affect animal performance. Lactating cows fed diets that contained a greater proportion of feeds (citrus pulp, beet pulp) that are high in soluble fiber and sugars, as compared to those fed diets containing more starch (from corn products), had lower intakes (Mansfield et al., 1994; Solomon et al., 2000), decreased milk protein % and yield (Leiva et al. 2000, Mansfield et al. 1994, Solomon et al., 2000), and increased butterfat % (Leiva et al. 2000, Mansfield et al., 1994) (Table 1). In another study, cows fed alfalfa silage-based diets containing 19% citrus pulp + 19% high moisture shell corn showed greater milk and protein yield responses to supplemental rumen escape protein from expeller soybean meal than did cows on 39% high moisture corn diets (Mertens et al., 1994). This suggested a poorer efficacy of nonprotein nitrogen utilization with citrus.

Substituting sucrose for starch appears to increase butterfat yield, but other results are mixed. In diets where sucrose was substituted for corn starch (0 to 7.5% of diet dry matter, diet NFC $\approx$ 43% of DM; Broderick et al., 2000), there were increases in dry matter intake, milk fat content and fat yield. Fat-corrected milk production tended to increase (Table 2). In terms of feed efficiency, milk / dry matter intake decreased from 1.60 to 1.52, and the conversion of ration nitrogen to milk protein N declined linearly with increasing substitution of sucrose for starch (from ~0.31 to ~0.29; G. Broderick, personal communication). When sucrose was substituted for corn meal at 1.5% of ration dry matter, intake, milk yield, and fat-corrected milk yield did not change, but milk fat yield increased from 2.12 to 2.14 lb per day, and milk protein % decreased from 3.51% to 3.28% (Nombekela and Murphy, 1995).

Table 2. Changes in milk yield and composition with changes in sucrose and starch supplementation. (Broderick et al., 2000). FCM = fat-corrected milk.

Sucrose%	Starch %	DM Intake, lb	Milk, lb	Milk Fat, lb	Milk Protein, lb	FCM, lb
0	7.5	54.0	85.8	3.24	2.73	89.3
2.5	5.0	56.4	89.1	3.37	2.82	93.0
5.0	2.5	57.3	88.2	3.64	2.84	96.8
7.5	0	57.3	86.9	3.57	2.82	95.2

Increased intake with sugar feeding may be related to improved diet palatability or increased rates of solid or liquid passage from the rumen. The results have been few and mixed regarding effects of sugar on passage. When glucose syrup equivalent to 16.8% of diet organic matter was infused into the rumen, organic matter passage to the small intestine increased (Jersey cows; Rooke et al., 1987). However, the glucose treatment did not differ from the control for the passage of organic matter per gram of organic matter intake. In a study with heifers, dextrose (5.6% of diet DM; 74.5% forage) did not affect the fluid dilution rate, but did increase the rate of solid passage from the rumen. This rate was similar to that of a ration containing more concentrate (48.34% forage) (Piwonka et al., 1994). Sucrose fed at 14.2% of ration dry matter increased ruminal fluid dilution rate as it decreased rumen fluid volume (sheep; Sutoh et al., 1996). These experiments suggest that sugars may affect rates of passage from the rumen.

It appears that altering the proportions of sugars, starch and soluble fiber can alter animal performance. However, most of these studies did not report the total amounts of the various NFC in the ration. That missing information is crucial if we are to evaluate what proportions of dietary sugars, starch or soluble fiber fed under what conditions will optimize performance.

Microbial Protein Yield and NFC

The apparent decreases in milk protein or efficiency of crude protein (CP) utilization noted with soluble fiber or sugars are perplexing. Both soluble fiber and sugars tend to ferment very rapidly in the rumen and should support good microbial growth if ruminal pH is not very acidic. Currently, the Beef NRC (1996) and some nutritional models (Russell et al., 1992) predict similar yields of microbes from NFC fermented in the rumen, when the substrates ferment at similar rates. Sugars and pectin (soluble fiber) are predicted to offer the greatest yields among the NFC because of their rapid rates of fermentation. These predictions seem to conflict with the animal performance data.

Microbial CP yields and their pattern of yield over time did differ among NFC in an in vitro fermentation study where microbial protein was estimated as trichloroacetic acid-precipitated CP (Hall and Herejk, 2001). When blends (40:60) of sucrose, citrus pectin, or corn starch and isolated bermudagrass NDF were fermented with mixed rumen microbes, the maximal yield of CP was greatest from the starch fermentation. The pectin and sucrose fermentations gave lower but similar yields at 88% and 86% of the microbial CP of starch. Lower yields of CP from the fermentations of sucrose and pectin could translate to reduced amounts of amino acids available to the cow, which would explain the reductions in milk protein in the animal studies. The results are consistent with the lower efficacy of NPN utilization, and the response to feeding rumen escape protein seen in the Mertens et al. (1994) study.

The patterns of CP yield across time also differed among fermentations (Figure 3). Pectin appeared to have a short lag period, fermented rapidly, peaked before starch, and then began to decline. Starch had the longest lag of the NFC, and peaked after pectin. Among the fermentation products, microbial mass is the one that is readily produced and degraded in the rumen. The rising portion of the curves likely indicate greater synthesis than degradation of microbial CP before the substrate becomes limiting, while degradation dominates in the declining portion of the curves (see Wells and Russell, 1996).

A variable that needs to be considered in predicting microbial yield from NFC, is that the microbes may not uniformly convert all available NFC to microbial products. Initially, sucrose fermented most rapidly, and then its microbial CP declined more slowly than the other substrates. This pattern may be explained by the ability of bacteria to store sucrose and other carbohydrates (glucose, fructose, maltose, cellobiose, fructans) as dextrans (microbial glycogen) (Thomas, 1960; Lou et al., 1997). Dextrans are composed of glucose, and has molecular linkages similar to starch. Rumen microbes may store up to ~18% of the original sugar substrate as dextrans (Thomas, 1960). Conversion of sugars to dextrans appears to be a survival mechanism, with microbes shifting from rapid growth and dextran storage, to maintenance and dextran use when sugars are depleted (Lou et al., 1997; Thomas, 1960). So, not all sugars are necessarily converted to microbial cells, organic acids, and gas, but some may pass to the small intestine as dextrans. Even on all forage rations (e.g., hay), there can be a significant flow of alpha-linked glucan (dextran) to the small intestine (Branco et al., 1999). Thus, microbes are capable of converting one type of carbohydrate into another, and this can change the metabolizable nutrients available to the cow.

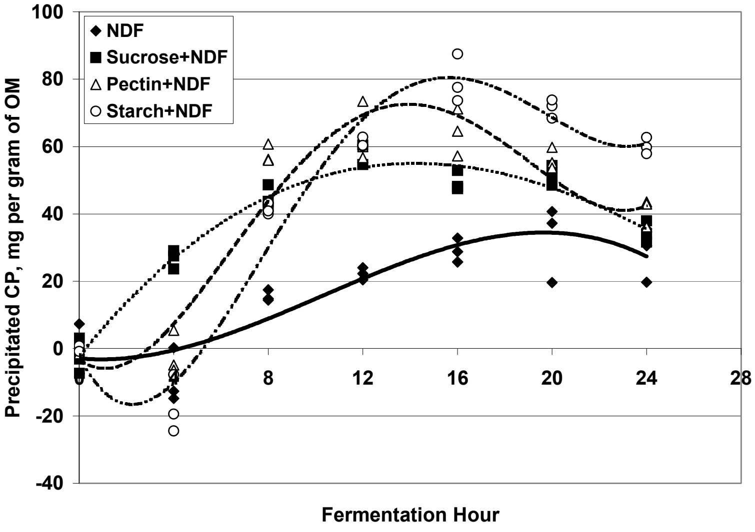


Figure 3. Precipitated crude protein yield curves from the fermentation of isolated bermudagrass NDF, and 60:40 blends of the NDF and sucrose, citrus pectin, or corn starch. Data from one fermentation. Precipitated CP should give a reasonable estimate of microbial CP. (modified from Hall and Herejk, 2001; reprinted with permission of Journal of Dairy Science).

Table 3. Equivalence of NFC by weight of simple sugars after hydrolysis, and proportion of usable carbons.

	Glucose (monosaccharide)	Sucrose (disaccharide)	Pectin (polysaccharide)	Starch (polysaccharide)
Dry weight, lb	1.00	1.00	1.00	1.00
Hydrolyzed weight, lb (hydrolyzed to simple sugars)	1.00	1.05	1.10	1.11
Predominant sugar	glucose	glucose + fructose	galacturonic acid (-/+ methoxyl group)	glucose
<u>Per sugar</u>				
Usable C/Total C[1]	6/6	6/6	6/6 & 6/7	6/6
Molecular Weight (MW)	180	180	203 (avg)	180
Weight of UC/MW	0.400	0.400	0.355	0.400
(UC/MW) x hydr. wt.	0.400	0.420	0.3905	0.444
% of starch value	90%	95%	88%	100%

[1] C = carbon

One other bit of food for thought: The differences in microbial yield are likely at least partially related to the monosaccharide composition of the carbohydrates as that affects the amount of carbon available for microbial use. Hydrolysis of the same dry weight of monosaccharides, disaccharides, and polysaccharides provide different amounts of monosaccharides (simple sugars such as glucose, fructose, etc.). For each bond between sugars that is hydrolyzed, the weight of one water is added (Table 3). Depending upon the degree of polymerization of the carbohydrates, we will have different weights of hydrolyzed sugars.

If we try to understand what microbial growth sugars (here for six carbon sugars; five carbon sugars are used with different efficiency) support, we can consider the number of carbons that are available for use by the microbes. In the cases of glucose or fructose, there are 6 usable carbons in each sugar. So, looking at usable carbon as a percentage of a sugar's molecular weight, glucose has (6 carbon x 12 m.w.)/(180 m.w. of Glc) = 72/180 = 0.400. For pectin (made up of galacturonic acid units), the value is (6 carbon x 12 m.w.)/(194 m.w. of GalA) = 0.371. The citrus pectin we used (Hall and Herejk, 2001) had 64% of the GalA units methoxylated, meaning that there was a methyl group bonded to the molecule. Gut microbes can cleave off that methyl group, releasing it as methanol (Siragusa et al., 1988). So, although the methyl group adds weight and a carbon to the molecule, it doesn't add usable carbon. The relationship between (usable carbon/molecular weight) x (weight of hydrolysis-released sugars) shows the same proportional difference between citrus pectin and starch as was seen for the maximal yield of microbial protein for these two substrates. That sucrose gave a lower yield of protein than predicted relative to starch probably relates back to the storage of carbohydrate as dextran, rather than its conversion to microbial cells.

Ration Formulation

The obvious question now is: "How should we formulate for NFC?" Darn good question. In an attempt to examine this issue, rations were obtained in a survey of U.S. lactating cow diets that supported high milk production and good health (Hall, unpublished). The NFC values for individual feeds were estimated using calculated NFC values (100-CP-NDF-EE-Ash). The proportions of NFC as sugars, starch and soluble fiber were estimated based on feed analyses previously performed in our laboratory (Hall, 2000). The nutritionists who provided the rations indicated that cows consumed rations resembling what was on paper. Some of the results of the survey are shown in Figure 4. Animal health can be affected by the types and amounts of NFC fed relative to amounts of forage/effective fiber in the ration, so NFC vs. forage values were compared.

Soluble fiber was relatively constant across forage levels. Starch and sugar contents varied inversely -- as forage content increased, starch increased and sugars decreased. **HOWEVER, those changes may be a function of feeds that were available in that geographic area, rather than deliberately formulating optimal rations.** On the low forage diets, citrus pulp which contains high levels of sugars (26%) and soluble fiber (33%) was typically included in the rations. Aside from citrus pulp, almond hulls, candy waste, some bakery waste, and molasses, there are not many sugar-rich feedstuffs available, but starch sources are abundant.

Possibilities To Consider:

- Pectins/Soluble Fiber: If they yield less microbial protein, inclusion of a greater proportion of rumen undegradable protein in the ration may be appropriate.
- Sugars: Sugars may yield less microbial protein than starch, but also provide starch ruminally and post-ruminally in the form of dextran (microbial glycogen). We do not fully understand what factors determine the microbe, organic acid, or dextran yields from sugars in the ration. It is likely that rumen pH will have some effect. Sugar sources may affect palatability, intake, and rates of passage from the rumen. Again, additional rumen undegradable protein feeding may be useful.
- Starch: Appears to offer the highest microbial crude protein yield, however, feeding high levels of starch have the potential to cause ruminal acidosis and digestive upset. We need to find out the extent to which sugars and starch are interchangeable to deliver a glucose source to the small intestine, and what proportions of soluble fiber, sugars, and total or physically effective NDF to include to offset the potential for ruminal acidosis.

For more information on different NFC types and feed composition, visit http://www.animal.ufl.edu/hall/. Go to the "Publication" section. There are a number of articles as well as a feed composition table (table 4 in this paper) in the carbohydrate lab manual.

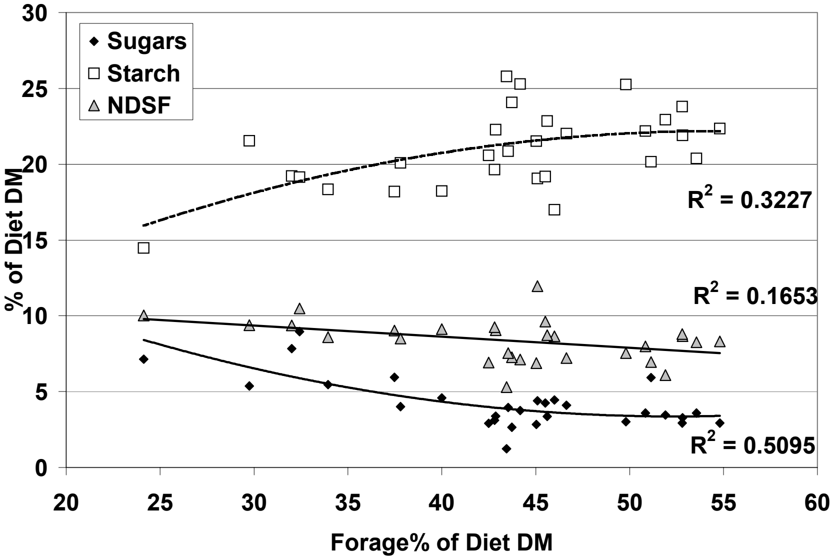


Figure 4. Estimated sugars, starch, and NDSF (soluble fiber) relative to the forage in the diets all as % of diet dry matter. (Hall, unpublished).

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Table 4. Feed composition values for analyses performed at the University of Florida through September 2001. Values are presented as a percentage of sample dry matter.[1]

Feed	Ash	CP	NDF	NDFCP	Organic Acids	Sugars	Starch	Soluble Fiber
Alfalfa Hay[3]					6	8	3	14
Alfalfa hay, CV						12.1	1.7	
Alfalfa hay, CV						8.2	4.5	
Alfalfa hay, FL 4/99	9.8	21.0	37.8	4.4		5.8	1.9	16.8
Alfalfa hay 1999	10.1	20.6	37.0	3.1		5.7	1.2	17.7
Alfalfa hay, CA, 8/99	7.2	21.6	43.3	5.0		6.8	1.6	19.1
Alfalfa hay, CA, 8/99	8.7	24.8	38.7	9.1		5.7	1.8	20.8
Alfalfa hay, CA, 8/99	12.9	25.6	32.0	7.9		5.1	3.4	19.8
Alfalfa hay, CA, 9/99	13.0	20.4	37.0	5.9		5.9	1.6	22.1
Alfalfa hay, CA, 9/99	11.9	29.4	34.2	6.0		6.0	2.0	16.0
Dehy. alfalfa pellets							4.0	17.6
Alfalfa silage, WH	9.5	19.1	45.5	2.1	10.4	1.8	0.7	12.1
Alfalfa silage, WH	11.3	18.1	38.1	2.0	14.2	1.1	1.4	13.3
Alfalfa silage, CV						7.7	1.1	
Alfalfa silage, CV						7.3	4.9	
Alfalfa silage average					12	2	1	12.5
Alfalfa stem, mature	7.8	12.4	58.0	2.3	4.6	7.2	0.3	10.8
Alfalfa stem, immature	14.0	18.5	32.9	1.3			0.4	16.9
Alfalfa leaf mature	10.5	31.5	22.2	3.1			1.0	18.4
Alfalfa leaf, immature	9.2	29.3	18.6	1.6	9.1	10.2	3.4	19.4
Almond hulls, WH	5.0	7.1	26.0	1.2	8.2	32.8	1.4	16.9
Almond hulls, CA 8/99	5.1	5.5	32.0	4.07		34.3	3.2	15.6
Almond hulls, CA 9/99	5.0	5.4	35.0	5.6		31.8	3.2	12.2
Almond skins, CA 8/01	6.0	12.2	33.0	2.4		14.7	0	10.7
Bakery waste, CA, 8/99	8.7	14.4	23.3	6.6		10.8	17.9	9.6
Broccoli	8.8	30.4	14.3	0.5	5.0	17.7	0.7	18.9
Canola meal, CA, 8/99	8.2	40.8	27.2	9.8		9.9	2.1	13.2
Canola meal, CA, 8/99	8.4	41.9	28.7	7.1		10.2	2.0	9.7
Canola meal, NM, 4/01	4.4		24.0	5.6		2.8	1.3	10.6
Citrus pulp, FL 4/99	8.5	8.7	24.1	4.2		13.4	1.4	37.5
Citrus pulp, FL 4/99	8.5	8.2	24.4	4.2		18.4	1.6	34.5
Citrus pulp, average[2]	6.7	7.2	22.1	2.9	9	26.5	1	32.9
Citrus pulp, ranges[1]	4.4-8.7	4.1-9.4	17.8-29.4	1.6 - 4.5		12.5-40.2		25.2-43.7
Corn distillers, ethanol						14.5	6.6	
Corn distillers, whiskey						6.2	4.2	
Corn distillers, FL 4/99	4.3	31.3	58.2	15.2		11.0	2.0	8.9
Corn distillers, FL 5/99	4.8	28.3	54.4	14.8		5.4	3.1	7.8
Corn distillers, 1999	4.3	30.3	46.3	12.7		3.2	0.5	11.6
Corn distillers, CA, 8/99	6.43	31.6	50.9	15.7		7.5	1.1	9.9
Corn gluten feed						5.9	16.4	
Corn grain, WH	1.5	9.0	12.6	0.7	0.7	0	64	8.1

Feed	**Ash**	**CP**	**NDF**	**NDFCP**	**Organic Acids**	**Sugars**	**Starch**	**Soluble Fiber**
Corn grain, CV						5.2	60.8	
Corn meal, FL 4/99	1.6	8.9	20.5	3.6		0	66.2	6.4
Corn meal, FL 5/99	3.3	9.0	15.7	3.8		4.5	55.9	10.6
Corn meal, 1999	1.1	9.5	11.8	2.9		2.3	65.8	8.6
Corn, rolled, CA 8/99	1.5	9.7	15.2	6.9		2.2	60.1	12.1
Corn, rolled, CA, 8/99	1.5	9.1	16.1	5.3		0.9	62.6	8.6
Corn silage, WH	4.9	7.5	50.9	0.9	10.6	0.9	18.9	4.3
Corn silage, WH	3.8	7.0	41.8	0.6	7.9	0.3	30.4	5.8
Corn silage, CV						3.4	14.4	
Corn silage, CV						4.7	29.9	
Corn silage, FL 4/99	4.8	10.2	51.1	4.4		0.5	19.4	7.0
Corn silage, FL 5/99	3.8	10.4	51.1	3.4		4.6	23.6	3.2
Corn silage, CA, 8/99	12.8	11.4	55.2	4.3		0.8	7.2	10.8
Corn silage, CA, 8/99	6.3	7.5	47.7	6.5		1.3	21.2	15.7
Corn silage, OH	12.1		47.1	1.6		3.3	18.1	11.1
Corn silage, OH	4.0		48.8	1.3		0.9	19.5	7.7
Cottonseed, whole							1	8.5
Ctsd whole, FL 4/99	4.2	24.2	48.3	5.3		6.2	1.6	6.8
Ctsd whole, FL 5/99	4.1	23.3	47.6	5.6		5.9	0.8	10.8
Cottonseed hulls							< 1	4
Green peas (frozen)	3.2	25.9	18.2	0.4	1.7	25.0	20.6	2.4
Molasses, cane						55+		
Oat hay, CA, 8/99	10.6	8.7	68.0	3.8		3.2	2.8	9.4
Potatoes						4.8	57.5	
Soybean meal (48%)	6.5	52.7	10.9	1.4	4.2	10.9	1.0	14.0
SBM (48%) FL 4/99	7.3	56.9	14.4	8.6		11.9	2.4	18.8
SBM (48%) FL 5/99	7.0	56.3	16.0	8.5		11.6	2.1	14.0
SBM (48%) 1999		56.7	9.7	3.2		10.2	0.5	16.9
Wet soy product, CA, 99	4.1	32.0	25.6	1.6		0.8	0.6	31.4
Soybean hulls	4.2	9.8	69.0	4.0	< 1	< 1	1	17.4
Sugar beet pulp, ID 3/94	8.9	8.0	44.6	5.1	0.4	12.8	0	30.0
Sugar beet pulp,CA 8/99	9.1	9.6	51.1	7.3		14.2	1.7	17.4
Sugar beet pulp,CA 8/99	7.4	9.8	39.8	5.7		24.7	2.3	20.1
Timothy hay	5.0	8.2	67.3	1.8	4.4	9.1	0.4	6.4
Ground wheat	1.7	10.9	12.1	1.1	0	1.8	64.6	8.8
Wheat middlings	5.5	19.0	42.3	3.4	4.6	5.4	21	3.4
Wheat silage, CA 9/99	12.4	12.8	50.8	6.1		2.5	2.7	16.8

[1] Capitalized abbreviations denote lab source, smaller font capitalized abbreviations indicate state and date of origin.

[2] Results from analyses of 79 dried citrus pulp samples.

[3] Alfalfa hay: soluble fiber content decreases with increasing maturity and with leaf loss.