Industry Presentation

Current Knowledge in Converting Starch and Fiber in Corn Silage into Milk

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INTRODUCTION

The concept of total digestible nutrients (**TDN**) has been a part of the foundation of ruminant nutrition since the early 1900s. In 2000, the National Research Council (**NRC**) published their revised Nutrient Requirements of Beef Cattle (NRC, 2000) and subsequently, their Nutrient Requirements of Dairy Cattle (NRC, 2001, **DNRC**). In these publications, the concept of the summative equation was proposed (Weiss et al., 1992) to enable the calculation of TDN from 21st century nutrients instead of using 20th century nutrients, as are in the original TDN equation. When using either of the TDN equations, practitioners of the science of ruminant nutrition should:

1) Use a cow-relevant particle size (6mm) for all measurements of digestion coefficients;
2) Deal with laboratories that replicate measurements (4 to 8);
3) Measure cow-relevant nutrients like dry matter (**DM**), starc,h and neutral detergent fiber (**NDF**); and
4) Measure as many values as possible…avoid calculated relationship values.

This paper will discuss some analytical offerings that can provide routine measurements of animal-relevant digestibility coefficients and show that the range in measured digestibility coefficients for total-tract starch digestion of whole-plant corn silage is: 77 to 98 %; different from DNRC of 90 or 98 % (before applying the processing adjustment factor).

In the original TDN equation, the nutrients were those that were measured by the analytical procedure known as proximate analysis: DM, crude protein (**CP**), crude fat, crude fiber, ash and nitrogen-free extract. In the summative equation, the nutrients became: truly digestible non-fiber carbohydrates (**tdNFC,** equation 2-4a, DNRC), truly digestible CP of forages (**tdCPf,** equation 2-4b, DNRC) or truly digestible CP of concentrates (**tdCPc**, equation 2-4c, DNRC), truly digestible fatty acids (**tdFA,** equation 2-4d, DNRC); and finally, truly digestible NDF (**tdNDF**, equation 2-4e, DNRC).

Practitioners using DNRC have one opportunity to input a measured digestibility value: "Digestible NDF can be obtained using a 48-hr rumen *in vitro* assay" (page 14, DNRC). All other equations (2-4a to 2-4d) calculate truly digestible nutrients from measurements of nutrient content. This paper will focus on 2 of the contributing terms to the overall equation that calculates TDN_{3x} using the summative concept, tdNFC and tdNDF, because these 2 terms are the sources of most of the variation in TDN to practitioners feeding corn, either whole-plant corn silage (**wpCS**) or forms of fermented corn grain (**HMC**). And it will discuss analytical procedures that give nutritionists measured values for starch digestibility (ruminal and total tract) and ruminal NDF digestibility.

DEGRADATION CALCULATIONS FOR NON-FIBER AND FIBER CARBOHYDRATES

The summative equation (Equation 2-4a, DNRC) defines tdNFC as:

tdNFC = 0.98 times (100 – [(NDF – NDICP) + CP + EE + ash]) times PAF

Where:

0.98 is the presumed apparent digestibility coefficient for NFC in the feed at TDN_{1x}; value should be reduced to 0.90 when calculating TDN_{3x},

NDF is neutral detergent fiber content of the DM in the feed,

NDICP is the nitrogen content of the NDF in the feed multiplied by 6.25,

CP is the nitrogen content of the DM in the feed multiplied by 6.25,

EE is the ether extract content of the DM in the feed,

Ash is the ash content of the DM in the feed, and

PAF is the processing adjustment factor of the feed.

The summative equation (Equation 2-4e, DNRC) defines tdNDF as:

$tdNDF = 0.75 \text{ times } (NDF_n - L) \text{ times } [1- (L/NDF_n)^{0.667}]$

Where:

0.75 is the factor that brings apparent digestibility of NDF from that measured at 96 hr to its value at 48 hr,

NDF_n is the result of (NDF – NDICP),

L is the lignin content of the DM measured as acid-detergent lignin, and

0.667 is the exponent that provides an adjustment to apparent digestibility of NDF due to the *encasement* of cellulose by lignin in the plant cell wall.

An alternative calculation for tdNFC proposed in this paper is:

tdNFC = SS + [eff STRD times (STR)] + [iDeg times (iSTR)]

Where:

SS is the soluble sugar content of the DM in the feed,

STR is the starch content of the DM in the feed,

eff STRD is the effective degradability of starch in the rumen measured as (K_{ds} / (K_{ds} + K_{ps})), in which **K_{ds}** is the rate of digestion of starch in the rumen and **K_{ps}** is the rate of passage of starch (Orskov and McDonald, 1979),

iDeg is the digestion coefficient of rumen by-pass starch, and

iSTR is the starch content that by-passes ruminal digestion.

An alternative calculation for tdNDF proposed in this paper is:

tdNDF = NDF times (eff NDFD)

Where:

NDF is the NDF content of the DM in the feed, and

eff NDFD is the effective degradability of NDF in the rumen measured as (K_{df} / (K_{df} + K_{pf})), in which **K_{df}** is the rate of digestion of forage NDF in

the rumen and **K_{pf}** is the rate of passage of forage NDF.

Sapienza Analytica, LLC (**SALLC**, Slater, IA) has developed a procedure for measuring ruminal rates of digestion (K_d) for DM, NDF, and STR under standard conditions and for measuring post-ruminal starch digestion. The measurement of rates of passage in animals is too resource intensive to be a routine measurement at feed analysis facilities.

Nutritional practitioners could submit a feed for measurement of **K_d DM** (rate of digestion of DM), K_{ds} and/or K_{df}. When the values for the rates of digestion are received, the practitioner could estimate the rate of passage for the DM in the total mixed ration (**TMR**) based on the level of production of the animals being observed or by a critical examination of dry matter intake (**DMI**) and fecal output.

Charles Sniffin (personal communication, 2000) has suggested the following formulas for calculating rate of passage of forages (K_{pf}) and concentrates (K_{pc}):

$K_{pf} = 0.388 + 0.022*(DMI/BW) + 0.0002*(DM^2)$

Where:

DMI = dry matter intake in grams,

BW = metabolic body weight in kilograms (weight (kg) $^{0.75}$),

DM = % DM in forage being fed, and

K_{pc} = 1.45*K_{pf} - 0.424.

Another possibility is to calculate a range of effective degradability (**eff D**) values for NDF by placing the measured K_{df} value into the equation (K_d/ (K_d + K_p)) for K_p values ranging from 0.04 to 0.06. In a similar way, nutritionists can calculate a range of effective degradability values for ruminal starch by placing the measured K_{ds} value into the equation for K_p values ranging from 0.06 to 0.12. The results of these calculations are in the matrix in Table 1. To complete Table 1 for an individual example, insert the value for K_p from the left column and the measured value for the appropriate K_d (K_d DM, K_{df} or K_{ds}) supplied by the analytical facility into the equation (eff D = K_d/ (K_d + K_p)). The calculated results are then placed into the appropriate cells in Table 1.

RUMINANT DIGESTIVE SYSTEM

The combination of a functioning rumen with its associated intestinal tract brings new analytical opportunities because practitioners must understand the site, extent, and rate of digestion for each of the nutrients in a feed. For this paper, the sites

Table 1. Matrix relating measured K_d values with estimates of K_p for calculating eff D.

K_p (x100)	K_d DM	K_{df}	K_{ds}
3	eff DMD	eff NDFD	
4	eff DMD	eff NDFD	
5	eff DMD	eff NDFD	
6	eff DMD	eff NDFD	eff STRD
8	eff DMD		eff STRD
10	eff DMD		eff STRD
12	eff DMD		eff STRD

will be limited to the rumen and post-rumen; extent will be the total quantity of DM, starch, and NDF that is digested in a specific time of digestion (for example 8, 12, 24, 30 or 48 hr of residence in the site of digestion); and rate will be the appropriate K_d. Dry matter and starch have measurable digestibility coefficients and rates in both the rumen and post-ruminally. The contribution of post-ruminal NDF digestion can be as high as 5 % with this percentage coming from hindgut fermentation (Firkins, 2006). It is possible that the fermentation products produced during hindgut fermentation are lost to the animal because they occur past the absorptive surfaces of the digestive tract. For this paper, we will ignore the contribution of energy coming from hindgut fermentation of NDF.

In Figure 1, 3 examples of unprocessed wpCS are presented. The classifications of high, medium, and low refer to the extent of ruminal digestion that was reached after 12 hr of ruminal *in vitro* (**IV**) digestion depicted in the shaded bar at the left of each of the classification sections (SALLC standard procedure using 6 mm particles in buffered rumen fluid). The additional height added to the ruminal IV digestion bars visualize the additional extent of digestion brought to 12 hr ruminal extent after 4, 8, or 16 hr of post-ruminal digestion [IV digestion that mimics gastric (approximate pH = 3) followed by illeal (approximate pH = 7.5) with semi-purified pancreatic enzymes (SALLC standard procedure)].

Figure 2 (Kleinmans, personal communication, 1995) visually represents the extent and site of starch digestion (measured in a similar way to that described for Figure 1) in 4 forms of corn - unprocessed wpCS, rolled corn grain, ensiled HMC, and steam flaked corn grain. In both Figures 1 and 2, the data presented illustrate that in situations where high amounts of starch are degraded in the rumen, less starch is degraded post-ruminally. The data also demonstrate

Figure 1. Shifting the site of starch digestion in samples of unprocessed wpCS.

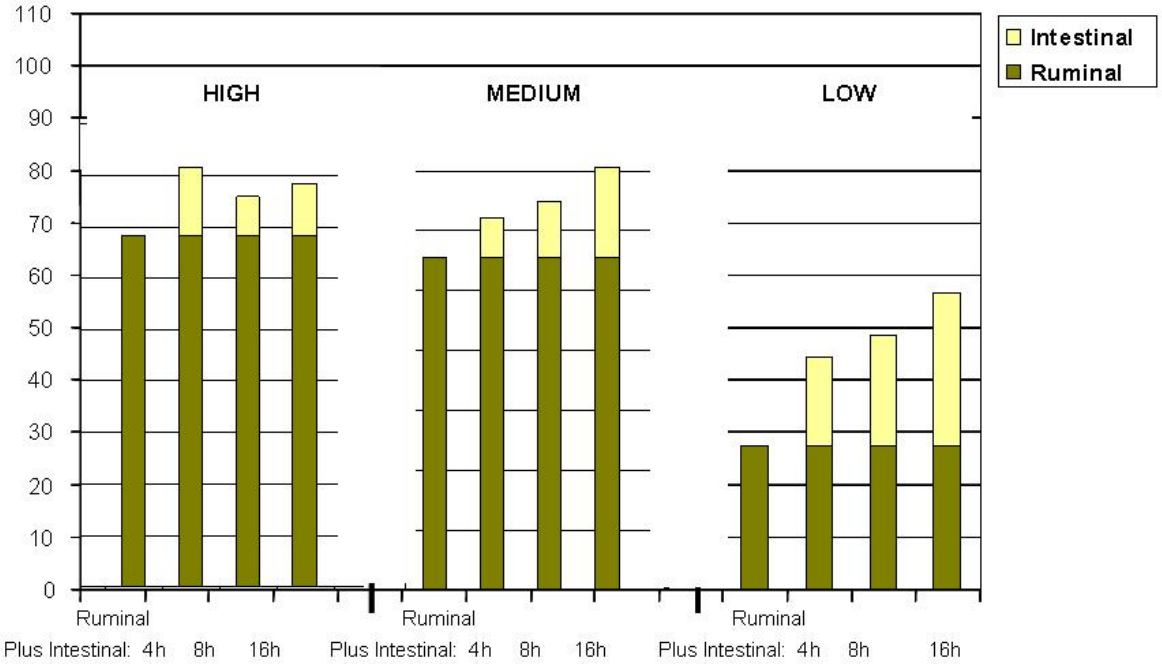
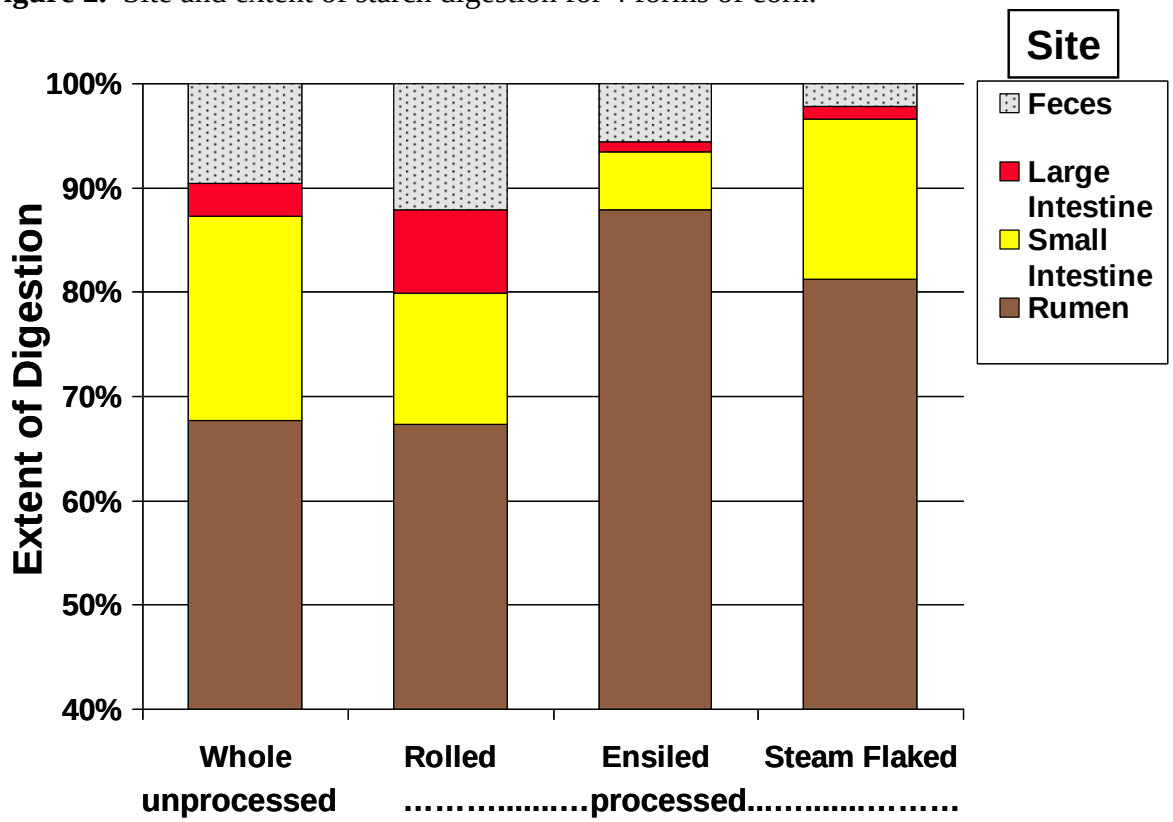


Figure 2. Site and extent of starch digestion for 4 forms of corn.



that post-ruminal starch digestion (small and large intestine) can approximate the quantity digested ruminally.

EXTENT OF STARCH DIGESTION

Dairyland Laboratories, Inc. (**DLI**, Arcadia, WI) has cooperated with SALLC in measuring starch digestibility in different samples of wpCS (Figure 3), different forms of processed corn (Table 2), corn grain from different corn hybrids (Figure 4); and digestibility of HMC at 2 lengths of time of ensiling.

The data in Figure 3 show that the average of 80 samples of wpCS submitted to DLI from practitioners throughout the United States is 82 % digestible, with a maximum of 97 and a minimum of 44 %. It shows that only 10 % of the samples submitted had a measured **STRD12** (ruminal starch digestion after 12 hr of IV ruminal incubation) greater than 87 %.

The data in Table 2 show the averages and ranges in STRD12 and total-tract STRD (**ttSTRD**) for the forms of processed corn listed. The range in ttSTRD for all forms of processed corn is from a minimum of 73 to a maximum of 98 % digestibility and the averages in ttSTRD for the 3 forms of processed corn are 80 (steam flaked), 85 (dry, shelled), and 94 (wpCS) % digestible.

Figure 3. Range in ruminal starch digestion after 12 hr of ruminal incubation.

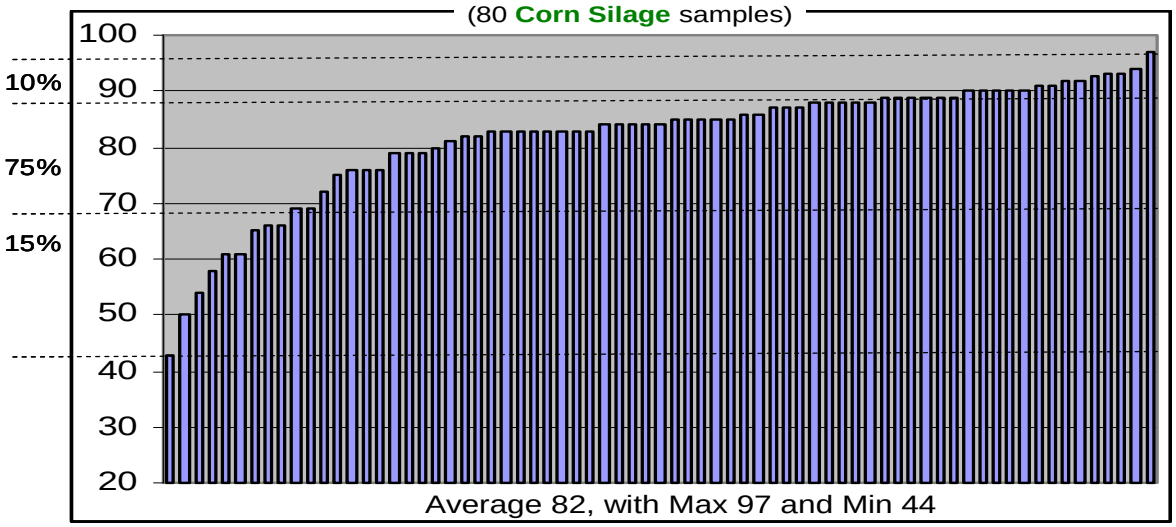


Figure 4 presents data measured in corn grain from 8 different hybrids. The range in STRD12 is from 19 to 57 % and in ttSTRD from 80 to 94 %. The data also show the percent contribution to ttSTRD coming from ruminal and post-ruminal starch digestion.

A practitioner sent samples of HMC from a silo on a dairy in Iowa. The first sample was submitted after about 60 d of ensiling and had a measured STRD12 of 68.1 %. The HMC was sampled about 120 d later and the STRD12 had risen to 85.5 %. The careful sampling and monitoring of the changes in STRD12 helped the practitioner reduce the incidences of lactic acidosis in the herd.

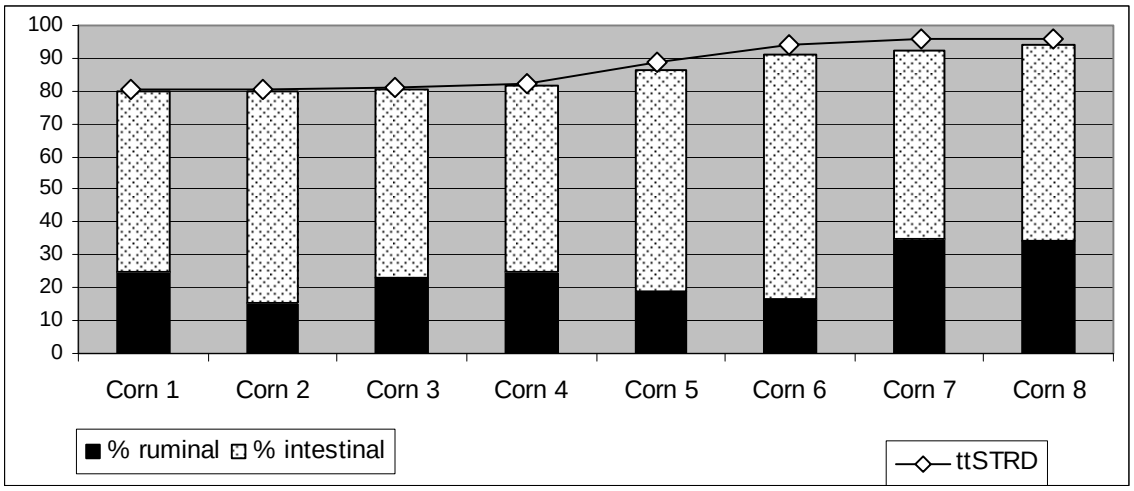
CONSIDERATIONS WHEN MEASURING STARCH DIGESTIBILITY

Practitioners of ruminant nutrition should consider some or all of the factors in the following discussion when measuring starch digestibility and request values for those factors that will or are having the most impact on the current situation or herd. Among the factors is particle size of the feed. The value to be requested from a

Table 2. Digestibility (ruminal and total tract) of different forms of processed corn.

Form of Processed Corn	Total Tract Starch Digestibility, % of Starch			
	Average	St. Dev.	Min	Max
Corn Silage	94	6.5	77	98
Dry Shelled Corn	85	5.7	79	92
Steam Flaked	80	5.4	73	88
	Ruminal Starch Digestibility 12 hr, % of Starch			
	Average	St. Dev.	Min	Max
Corn Silage	84	11.6	45	98
Dry Shelled Corn	45	17.8	20	65
Steam Flaked	70	10	55	83

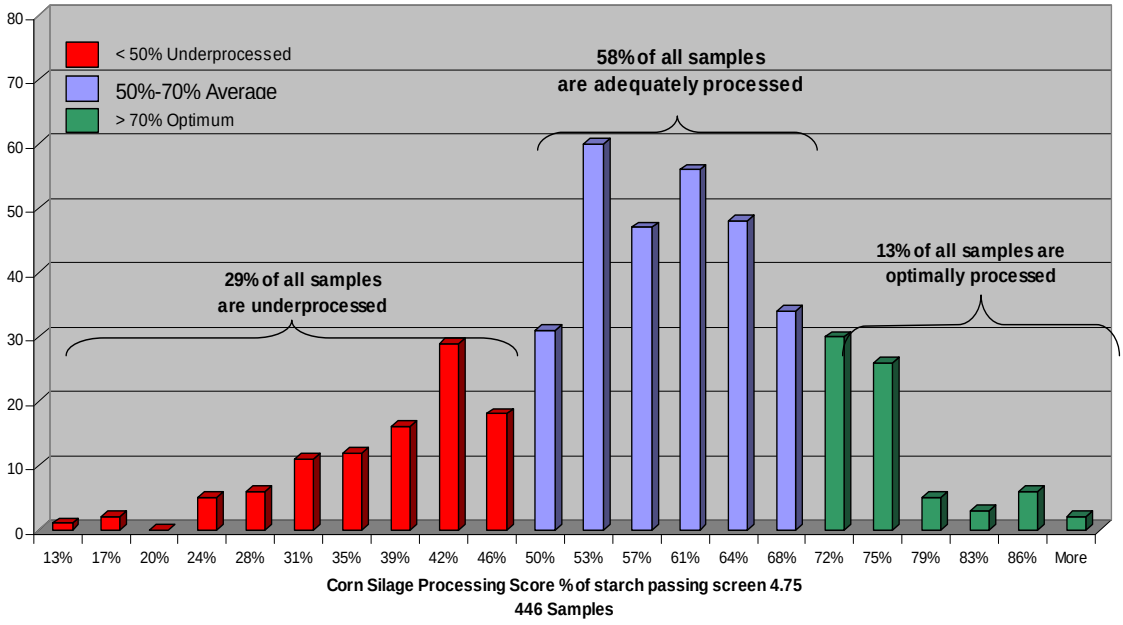
Figure 4. Hybrid differences in ruminal starch digestion after 12 hr of IV ruminal digestion (**STRD12**), total tract starch digestion (**ttSTRD**) and percent contribution to ttSTRD.



laboratory to quantify this is either the Corn Silage Processing Score (**CSPS**, available at DLI) for wpCS or a sieve analysis for ground corn (HMC or ground, dry grain). DLI measured the CSPS in 446 samples to generate Figure 5. Of the submitted samples, 28 % were underprocessed; indicating that the particle size of the wpCS being fed to those herds is larger than optimum and digestion is decreased (Bal et al., 2000).

Further, the practitioner should question the laboratory and determine if the particle size of the submitted sample, that will eventually be analyzed for digestibility (*in vitro* or *in situ*), will be at a cow-relevant particle size. Particle sizes in use in commercial feed testing laboratories are sometimes dependent upon the recommended analytical procedure of the proponent agency, such as the American Association of Analytical

Figure 5. Distribution of corn silage processing scores among samples submitted to Dairyland Laboratories, Inc.

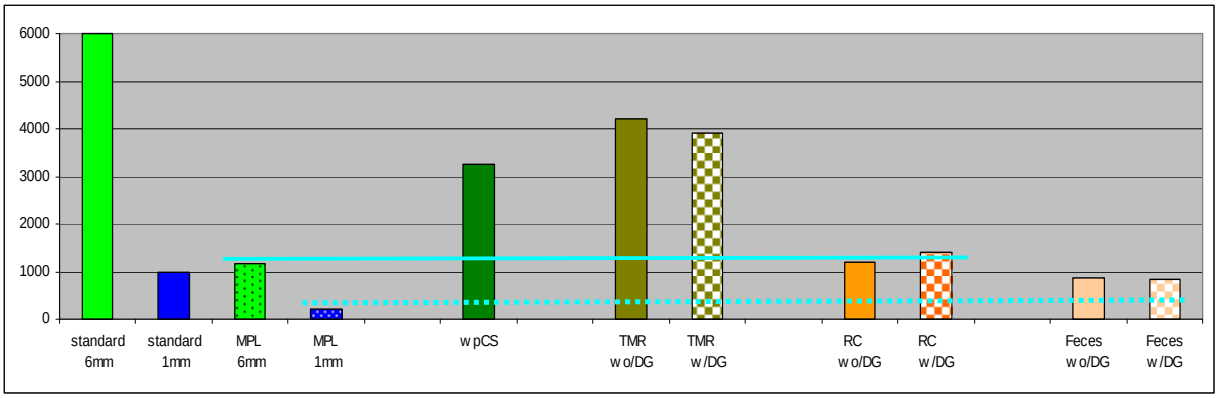


Chemists (**AOAC**) and the National Forage Testing Association (**NFTA**). In most cases, the recommended particle size is 1 to 2 mm ground through a Wiley Mill (Thomas Scientific, Swedesboro, NJ). In the case of samples submitted for analysis by Near Infrared Spectroscopy (**NIR** or **NIRS**), the recommended particle size is 1 mm passed through an abrasive grinder.

For digestion measurements (*in vitro* or *in situ*), there are neither recommended procedures nor particle sizes from either AOAC or NFTA. In 2004 Larry Chase surveyed forage and feed testing facilities that offered *in vitro* NDFD measurements (Chase, 2004). Four entities used 1 mm particles from a Wiley Mill (shearing type) and six used 1 mm particles from a Udy Mill (abrasive type, Fort Collins, CO). The incubation systems employed were: three used flasks in a water bath with recovery of digesta by filtering; one used tubes in a water bath with recovery by centrifugation; and six used the Daisy Incubators (Ankom, Macedon, NY). Times of incubation ranged from 6 to 48 hr with 48 hr being most common. Five entities used the Van Soest buffer and five used the Ankom buffer. There were variations in handling of donor animals; their rations; and rumen fluid from the donor animal to the *in vitro* incubation, as well as how analytical consistency was measured.

The SALLC standard procedure (not included in Chase's survey because SALLC was not yet operational) is to use 6 mm particles from a Wiley Mill. A known amount of the dry, ground plant material is weighed (500 to 1000 mg) into 5 x 10 cm Dacron bags (Ankom). A minimum number of 4 replicates for each sample are placed into a container of buffered rumen fluid (Van Soest buffer). The rumen fluid is collected on site, not filtered, and maintained at a constant temperature and purged with CO_2 for the 20 min from collection to incubation. The incubation vessels are placed into an air-jacketed, anaerobic incubator (Shelton Manufacturing, Portland, OR) for the client-specified incubation times ranging from 2 to 72 hr. SALLC uses 4 donor animals/incubation. Animals are fed a ration that is approximately 75 % (DM basis) of the forage being tested. SALLC monitors

Figure 6. Cow-relevant particle size for digestion measurements where MPL = mean particle length; wpCS = whole-plant corn silage; TMR = total mixed ration; DG = distillers grains; and RC = rumen contents.



analytical consistency by incubating 4 replicates of its digestion standard (wpCS) in each incubation and at each time of incubation.

SALLC measured the particle sizes and mean particle length (**MPL**; ANSI, 1998 and Leonardi et al., 2005) of diet ingredients, the resultant TMR, ruminal contents, and feces in a group of steers being fed TMR with or without distillers' grains. The data are shown in Figure 6 with a clear indication that the cow-relevant particle size to be used when making digestion measurements is approximately 6 mm or a particle size distribution that has 70 % of the particles 6 to 8 mm.

Another indication that the cow-relevant particle size (6 to 8 mm) to be used when making digestion measurements is supported with data in Table 3. In this experiment, *in situ* digestion measurements were performed on the same plant material that was being used in an *in vivo* milk production and total collection dry matter digestibility (**DMD**) trial (Johnson et al., 2002).

Particle size of the digested sample is important when measuring NDFD at any of the popular times of incubation (24, 30 or 48 hr). SALLC measured ruminal *in vitro* digestion of NDF at multiple hours of incubation in samples coming from diverse corn hybrids. The hybrids were part of a corn breeding program whose objective was to improve NDFD. Table 4 shows that the digestibility measurements made at any of the 3 hr of incubation were numerically greater for conventional (**CON**) at 1 mm

Table 3. Cow-relevant measurements, *in situ* and *in vivo*.

NDFD 24	Treatments				
	Fresh ≥ 8mm	Dried ≥ 8mm	Dried ≥ 4mm	Dried ≥ 3mm	Dried ≥ 2mm
	24-hour ruminal *in situ* NDF disappearance				
mid-maturity	28.7[a]	31.8[c]	22.5	27.8	28.6
late-maturity	19.2[b]	23.1[d]	29.7	33.8	28.4
				Inverted ranking	
STRD 24	Treatments				
	Fresh ≥ 8mm	Dried ≥ 8mm	Dried ≥ 4mm	Dried ≥ 3mm	Dried ≥ 2mm
	24-hour ruminal *in situ* starch disappearance				
mid-maturity	82.5[a]	82.3[c]	97.0	98.2	97.3
late-maturity	52.2[b]	71.2[d]	95.3	93.9	91.4
				No difference	

	In vivo Performance	
	% DMD	Milk lbs/c/d
mid-maturity	71[a]	82[a]
late-maturity	52[b]	79[b]

[a, b] $P < 0.05$.
[c. d] $P < 0.05$.

Table 4. Comparisons in NDFD using 1 mm vs. 6 mm particles and multiple hours of incubation.

	Dry Matter	NDF	NDFD 24	NDFD 30	NDFD 48	DMD 24	DMD 30	DMD 48
IMP average (1 mm)	30.74	45.38	39.23	46.27	56.30	72.57	75.73	80.13
IMP average (6 mm)	33.13	42.98	31.26	40.91	50.15	57.72	61.89	66.83
Con average (1 mm)	36.29	45.89	40.38	49.63	56.69	72.69	76.88	81.19
Con average (6 mm)	34.46	40.25	24.21	30.85	42.98	50.32	59.37	68.51

than for improved (**IMP**) at 1 mm. This conclusion was opposite of the IV data generated at 6 mm and opposite of animal data generated for the same groups of germplasm. The data in Tables 3 and 4 show that when STRD or NDFD measurements are performed using 1 mm particles, the chance exists, to reverse the comparisons or to show no differences, especially after 48 hr of ruminal incubation.

Considerations for nutritionists before asking a feed-analysis facility for measurements of both starch and NDF digestibility are:

1) The contributions of crop maturity (Table 3),
2) Degree of crop processing (especially if a CSPS will not be measured), and
3) Length of ensiling time (Figure 3).

These observations should be made by the nutritionist at the time the sample is collected.

Total-tract starch digestion is the sum of the contributions of ruminal and post-ruminal digestion. As shown in Figures 1, 2, and 4 and Table 2, there are compensatory effects; low ruminal starch digestion can result in an increase in the amount of digestion that occurs post-ruminally. Nutritionists must be aware of ruminal starch digestion in relationship to incidences of lactic acidosis or extent of sub-acute ruminal acidosis (**SARA**). Table 5 (Andrighetto et al., 1998) illustrates the interactivity of the compensatory effects in terms of milk production. The first row of the table shows the range in ruminal STRD for the treatments, 59 to 81 %. Rows 2 to 7 show a non-significant effect on animal-relevant production observations.

Table 5. Compensatory effects of site of digestion on milk production.

Observation	Hard	Soft	HMC	H vs S	HS vs HMC
In-situ DDM, %	59.2	65.8	81.4	0.01	0.01
DMI, kg/d	19.2	18.7	17.0	ns	0.05
Milk yield, kg/d	31.8	31.4	31.4	ns	ns
Yield 4% FCM, kg/d	29.9	30.0	28.5	ns	ns
FCM / DMI	1.56	1.60	1.68	ns	ns
Milk fat, %	3.60	3.70	3.38	ns	0.10
Milk protein, %	3.19	3.17	3.18	ns	ns
Acetate: Prop ratio	2.8	2.8	2.5	ns	0.10
Ruminal NH3, mg/dl	11.4	9.9	6.8	0.10	0.01
PUN, mg/dl	15.0	13.9	11.8	ns	0.01

CONCLUSIONS

Obtaining rates of ruminal degradation of starch and NDF and using those measured values to calculate eff STRD and eff NDFD, practitioners of ruminant nutrition can approach the TDN equation (21st Century version) with digestion coefficients for multiple production levels in cattle. Practitioners can capture the variation that actually exists in corn germplasm for ruminant digestion of starch and NDF and for ttSTRD. The data show that the range of ttSTRD in different forms of corn, as measured by commercial feed testing facilities, can range from 44 to 97 % with an average of 82 %. The conventionally accepted range of 90 to 98 % may not fully capture the variation that exists in production agriculture today.

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