UNDERLYING FIBER CONCEPTS AND DEFINITIONS[1]

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INTRODUCTION

Fiber is the indigestible and slowly digesting fraction of a feed that occupies space in the gastrointestinal tract. Its unique properties cause fiber to affect intake, digestibility, passage and ruminal function. Fiber is a nutritional entity that we measure by chemical insolubility, and neutral detergent fiber (NDF) is the best measure of insoluble fiber for ruminants. However, the nonfiber fraction, neutral detergent solubles (NDS), has ideal digestive properties, in that it is almost completely digestible with a constant endogenous loss. The unique and distinct digestive properties of NDF and NDS allows dry matter digestibility (DMD) to be predicted by a simple summative equation, which indicates that DMD is related wholly to NDF and its digestibility. The development of the NDF method (Van Soest and Wine, 1967) is arguably the most important analysis for feed evaluation and ruminant nutrition (Mertens, 1993).

The next most important development in fiber digestion was speculation by Waldo (1969) who suggested that cellulose may be divided into digestible and indigestible fractions, and that the kinetics of the digestible fraction would be first-order. Waldo (1969) cited the work of Wilkens (1969) who used 6-day in vitro fermentations to determine potentially digestible cellulose. The concept that fiber contained an indigestible fraction was the key to defining digestion kinetics and Waldo et al. (1972) described the mathematics of first-order digestion of fiber. Smith et al. (1972) used 72-h fermentations to define indigestible NDF in a 2-pool model, and demonstrated that the potentially digestible NDF followed first-order kinetics. This 2-pool model of NDF digestion has proven useful for nearly 40 years. Mertens (1973, 1977) reported that using fermentations longer that 72 h indicated that a 3-pool model most accurately described long-term fermentations. Mertens and Ely (1979, 1982) developed a simulation model that used 3-pools for both digestion and passage of NDF. More recently, Raffrenatto and Van Amburgh (2010) have used fermentations of 120 or 240 h to define the indigestible NDF fraction for 3-pool models.

The objectives of this presentation are to review some of the crucial concepts of NDF analysis and digestion and to present recommended definitions of fiber and in vitro results that may improve our communications for feed evaluation and kinetic modeling.

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CONCEPTS

Fiber (Insoluble Fiber)

Fiber is a nutritional entity, not a chemical one. For ruminants, fiber is the indigestible or slowly digesting fraction of a feed or diet that occupies space in the gastrointestinal (GI) tract. Neutral detergent fiber is our best estimate of insoluble fiber. The method was designed to solublize the easily fermented and digested fractions of feeds. Fiber is related to the digestibility of a feed or diet because it is less digestible than solubles. Because it occupies space it affects ruminal fill and intake. Although it is not a part of the fiber definition, the physical form of fiber also has important effects on ruminal function and passage of feeds through the gastrointestinal tract.

Although they are highly correlated, NDF is not equivalent to plant cell walls because NDF dissolves pectin (a component of cell walls) that is highly fermentable and therefore does not fit the definition of fiber for ruminants. For non-ruminants, fiber is defined as any constituent that cannot be hydrolyzed by enzymes in the GI tract. Because some of these constituents can be easily solubilized, fiber for non-ruminants consists of both soluble and insoluble fiber. Most soluble fibers are easily fermented in the rumen; thus, insoluble fiber (NDF) is the primary fiber of interest in ruminants.

Digestibility (True versus Apparent)

Second only to intake, digestibility is important in affecting how feeds or diets influence animal performance. Digestibility of fiber is of singular importance because its true digestibility varies so greatly among feeds when compared to protein, fat or sugars. Apparent digestibility of most nutrients is the net disappearance of the nutrient as it passes through the GI tract. The digestibility is apparent, and not true, because the feces can contain nutrients from endogenous losses (microbial debris, sloughed cells or intestinal secretions). The Lucas regression of apparently digested nutrient (% of DM) versus nutrient content (% of DM) provides an estimate of both true digestibility and endogenous loss. Technically, the Lucas test should be used with in vivo digestibility measured at maintenance levels of intake, so that intake and rate of passage do not vary appreciably among feeds. A typical Lucas regression for crude protein (CP) is:
$dCP = -3.5 + 0.93*CP$; were dCP is apparently digested CP (% of DM) and CP is crude protein concentration (% of DM). The regression coefficient of this regression indicates that CP true digestibility is 0.93 across all feeds and the intercept indicates an endogenous loss of 3.8 %-units of CP when there is no CP in the feed.

Fiber is unique among nutrients because it has no endogenous loss (neither animal nor microbes generate fiber). Thus, the apparent and true digestibility of fiber are the same. However, it is possible to dry feces improperly and create artifact fiber that would then appear to be endogenous loss. Fiber is also unique because its digestibility is not uniform across or within feed types. One of the underappreciated aspects of NDF analysis is that it separates feeds into a fraction with variable digestibility (NDF) and a fraction with uniform digestibility (NDS - neutral detergent solubles). The consequence of

this separation is that a simple summative equation can be derived to estimate dry matter digestibility of forages from only two measurements (NDF and its digestibility - NDFD):

$$DMD = NDF*NDFD + 0.98*(100 - NDF) - 12.9.$$

This equation indicates that the primary factors affecting digestibility are NDF and NDFD. The large endogenous loss for DM (12.9 %-units of DM) suggests that it may include ash which passes through the animal. Starch may be another nutrient that may complicate the simple summative equation. At maintenance levels of intake, starch that is not finely ground may be chewed adequately to attain 0.98 digestibility. However, at higher intakes and coarser particle sizes, starch will also have variable digestibility.

A critique often heard is that NDF is so variable among feeds that its usefulness in ration formulation should be suspect. However, the variability within NDF is much less than its difference from NDS. Although NDF is variable in composition, digestibility and particle size (especially when feeds are chopped and ground), it is still supremely valuable in separating feed into highly digestible (NDS) and lower and more variably digestible fiber (NDF) fractions. The non-uniform characteristics of NDFD suggest that NDF may contain fractions with unique, but different, digestion properties. We know that NDF contains lignin that is not digestible, which explains, in part, why NDF has non-uniform digestibility. However, the digestion kinetics of fiber indicates that there is a much larger fraction of NDF that is not digestible in anaerobic fermentations, the so-called indigestible NDF (iNDF). Mertens (2002) suggested that, if the iNDF is subtracted from total NDF, the resulting digestible NDF fraction may have much more uniform digestibility. Furthermore, if ash is removed from both fiber and non-fiber component, the variation in digestibility related to ash could be eliminated. These modifications would result in a new summative equation that may be more useful:

$$dOM = pdNDFOMD*(aNDFOM - iNDFOM) + 1.00*(OM - aNDFOM) - EL;$$ where dOM = digestible OM, pdNDFOMD = digestion coefficient of the potentially digestible NDF organic matter, aNDFOM = amylase-treated NDF organic matter, iNDFOM - indigestible NDF organic matter, OM = organic matter, and EL = endogenous loss.

Digested versus Digestible Nutrients

Before leaving the topic of digestion, it is important to discuss some concepts about terminology that need to be addressed to aid our communication with clients and colleagues. By long tradition, we have referred to digestible nutrients in DM, e.g., digestible CP. However, "digestible" is a misnomer. The term "digestible" literally means "can be digested." We rarely, if ever, measure what "can be digested", but we do measure what "is digested." Therefore, we should have defined these feed fractions as "digested" and not "digestible" nutrients, e.g. digested CP. This crucial distinction becomes apparent when we introduce kinetic parameters. The pools in digestion models are digestible or indigestible, by definition. They are theoretical constructs upon which the model is designed. What we measure are undigested or digested fractions. Literally, "undigestible" and "indigestible" mean the same thing, "that which can never be digested." The term "indigestible" was selected so that we could differentiate it from "undigested." Thus,

measurements are defined as digested NDF (dNDF) or undigested (uNDF), but the model parameter is indigestible NDF (iNDF), which will never digest in the ruminal environment. We can never measure iNDF (requires infinite time), but it can be approximated by uNDF measured after long-term fermentations.

Digestion coefficients and digested nutrients are related, but are not inter-changeable. It is important to use acronyms that clearly distinguish between the two. It is recommended that lower case "d" be used as a prefix to identify "digested" nutrients as a percentage of DM, e.g., dNDF (% of DM). Then the suffix upper case "D" can be used to denote a digestion coefficient, e.g., NDFD (decimal fraction or % of NDF). I also recommend that digestion coefficients or digestibilities be express as decimal fractions to further distinguish them from digested nutrients (% of DM). It makes little sense to convert a number to percent by multiplying by 100, and then having to divide the percentage by 100 to use the number. The following equations demonstrate the relationship between digested NDF (20% of DM) and its digestion coefficient (0.500) for a feed with 40% NDF (% of DM):

$dNDF(\% \text{ of } DM) = NDFD*NDF(\% \text{ of } DM) = 0.500*40(\% \text{ of } DM) = 20(\% \text{ of } DM)$
$NDFD = dNDF(\% \text{ of } DM) / NDF(\% \text{ of } DM) = 20(\% \text{ of } DM) / 40(\% \text{of } DM) = 0.500.$

In vitro (IV) digestibilities are often reported with a subscript to indicate the time of fermentation used for the measurement. Although fermentation time is important, many other variables within the in vitro method can significantly affect results (Boyd and Mertens, 2011).

First-order kinetics

Models are representations that are always simplifications of reality. We should never delude ourselves that they are reality, and fully appreciate that they need only to have enough complexity to serve our purposes. The 2-pool model of digestion or fermentation has served us well in describing the digestion process:

$NDFRes_{(t)} = D'*e^{(-kd*t)} + I_2$; where $NDFRes_{(t)}$ is the $uNDF_{(t)}$ remaining after any time = t, D' is potentially digestible NDF at t=0, kd is the first-order fractional rate constant for digestion, and I_2 is iNDF for a two-pool model. Smith et al. (1972) used a 72h in vitro to estimate the iNDF (I_2) for the two pool model. The model equation can be rearranged to provide a regression equation similar to the semi-log plots by subtracting I_2 from each side of the equation and taking the natural logarithm of each side:
$(NDFRes_{(t)} - I_2) = D'*e^{(-kd*t)}$

$\ln(NDFRes_{(t)} - I_2) = \ln(D') - kd*t$, which can be solved by regression to obtain kd as the regression coefficient. Fiber typically has a discrete lag time before digestion begins, which can be calculated after the kd is determined:
$\ln(NDFRes_{(0)} - I_2) = \ln(D') - kd*Lag,$

[ln(NDFRes$_{(0)}$ - I$_2$) - ln(D')] / -kd = Lag; where NDFRes$_{(0)}$ is the NDF content of the feed, kd is known and Lag is the discrete lag time. The potentially digestible NDF at t=Lag is D$_0$, such that D$_0$ + I$_2$ = total NDF:

ln(D$_0$) = ln(D') - kd*Lag; where D', kd, and Lag are known.

When fermentation times longer than 72h were obtained, the semi-log plot of ln(NDFRes(t) - I$_{>72h}$) is often curvilinear, which indicates that either there is more than one potentially digestible pool or that the digestion process was not first-order. Curve peeling indicates that a 3-pool model could mimic observations when long-term fermentations were generated:

NDFRes$_{(t)}$ = F*e$^{(-kdf*[t - Lag])}$ + S*e$^{(-kds*[t - Lag])}$ + I$_3$; where NDFRes$_{(t)}$ is the uNDF$_{(t)}$ remaining after any time = t, F is fast digestible NDF, S is slow digestible NDF, kdf is the first-order fractional rate constant for digestion of F, kds is the first-order fractional rate constant for digestion of S, Lag is the discrete time of fermentation before digestion begins so that F + S + I$_3$ = total NDF, and I$_3$ is the iNDF for a three-pool model. Lag time is assumed to be the same for F and S to simplify the model.

Indigestible NDF is a model as well as a biological concept. Biologically, it is the NDF that cannot ferment in the anaerobic environment of the rumen and is highly correlated with lignin (Smith et al, 1972; Traxler et al, 1998). Some have suggested that it is not an inherent characteristic of NDF because it can be altered if ruminal conditions are changed (high grain diets). But the concept of iNDF is useful in building models of fiber digestion that mimic reality. Mathematically, I$_2$ cannot equal I$_3$ unless S = 0, and then the 3-pool becomes a 2-pool model. Although biologically it is impossible to have two different iNDF for a feed (at infinite time, only one iNDF can exist), from a modeling perspective, it is quite possible to have two iNDF (I$_2$ versus I$_3$) because the model itself defines what iNDF must be. It all depends on how closely you want to predict fermentation after 48 h. Mertens (2011) observed that when a 2-pool model is used to fit 3-pool data, the slow-digesting pool (S) is divided between the I$_2$ and D$_0$ pools. Thus, I$_2$ will be larger than I$_3$.

DEFINITIONS

I apologize that the acronyms for fiber, digestion, and kinetics have become longer and more complex, but it is necessary to indicate distinctions that not only affect the value or magnitude of the number, but also influence our communication about the model and real world. Simplify these acronyms at your own risk! Not only can simplified acronyms muddy our thinking, but it can greatly increase the confusion of clients and colleagues. To avoid or minimize confusion, both the acronym and the units should be reported. The prefix "IV" can be changed to "IS" to indicate the in situ bag method and the prefix "IV" can be eliminated to indicate in vivo measurements in the following acronyms.

ADF - Acid Detergent Fiber (% of DM). Fiber residue after extraction for 60 min in acid detergent solution. ADF was developed as a preparatory step for the determination of lignin. It is not an estimate of total insoluble fiber because hemicellulosic carbohydrates are dissolved. Because acid detergent extracts protein more effectively than neutral

detergent, ADF is a better preparation technique for measuring lignin, which can be contaminated by protein.

ADFseq - Acid Detergent Fiber sequentially extracted after neutral detergent extraction (% of DM). Neutral detergent extracts pectin and some non-lignin phenols better than acid detergent. When the difference between ADF and NDF is small or when high pectin contents are expected, sequential extraction of ADF results in more accurate estimates of hemicellulose (see HC definition) and perhaps of lignin.

HC - Hemicellulose (% of DM). A crude estimate of hemicellulose can be obtained by subtracting ADF from aNDF: HC (% of DM) = aNDF (% of DM) - ADF (% of DM). Do not use aNDFOM (% of DM) in this equation because ADFOM is typically not measured by ashing the fiber because the ADF is used for lignin analysis.

HCseq - Hemicellulose determined when sequential ADF is used for its calculation (% of DM). An alternative estimate of hemicellulose can be obtained by the equation: HCseq (% of DM) = aNDF (% of DM) - ADFseq (% of DM). See definition for ADFseq.

KLig - Permanganate lignin (% of DM is preferred over % of NDF). Permanganate lignin is determined on acid detergent residue by oxidizing and removing the lignin, which is determined as the difference between ADF and cellulose residue. The suffix "seq" can be added to KLig, if the ADF was determined sequentially.

SLig - Sulfuric acid lignin (% of DM is preferred over % of NDF). Sulfuric acid lignin is determined on acid detergent residue by dissolving cellulose in 72% sulfuric acid and measuring the ash-free lignin residue. SLig typically results in lower values than KLig (Mertens, 1973):

SLig = .164 + 0.755*KLig (Grasses) and
SLig = .995 + 0.660*KLig (Legumes).

The suffix "seq" can be added to SLig, if the ADF was determined sequentially.

ADL - Acid Detergent Lignin (% of DM). This is an obsolete acronym that should no longer be used because it does not distinguish between KLig or SLig. The method for lignin determination should be indicated because the two methods do not give the same results (see SLig definition).

ADFCP - Acid Detergent Fiber Crude Protein. ADFCP is an obsolete acronym that should not be used because it can be confused to mean the CP in ADF.

ADICP - Acid Detergent Insoluble Crude Protein (% of DM or % of CP, but never % of ADF). Acid detergent insoluble crude protein is an estimate of inherent insoluble nitrogen in feeds as well as nitrogen tightly bound in amino acid and sugar complexes created during heating in the presence of moisture (Maillard reaction). ADICP is calculated as ADIN*6.25 (see definition of aNDICP for problems with this assumption).

ADIN - Acid Detergent Insoluble N (% of N). ADIN is an obsolete acronym that should not be used because it has only limited value in some equations for calculating crude protein digestibility when feeds are heat-damaged. ADICP (% of CP) can be used in the place of ADIN in these equations.

NDFCP - Neutral Detergent Fiber Crude Protein. NDFCP is an obsolete acronym that should not be used because it can be confused to mean the CP in NDF instead of a measure of protein that has specific attributes.

NDICP - Neutral Detergent Insoluble Crude Protein (% of DM or % of CP, but never % of NDF). When extracted by neutral detergent without sodium sulfite (as in the NDR, but not the NDF or aNDF methods), NDICP is used as an estimate of slowly degrading protein in some models. NDICP can be used to correct NDR for protein contamination, but should not be used to correct NDF or aNDF, which are methods that use sodium sulfite (see definition for aNDICP). NDICP is calculated as NDIN*6.25 (see definition of aNDICP for problems with this assumption).

aNDICP - amylase-treated Neutral Detergent Insoluble Crude Protein (% of DM). When extracted by neutral detergent with sodium sulfite (as in the NDF or aNDF methods), aNDICP can be used to correct NDF or aNDF for protein contamination. NDICP is calculated as NDIN*6.25; however, Maillard products usually contain one amino acid and one sugar molecule. Therefore, Maillard products contain about 8% N instead of the 16% N in amino acids and 6.25 coefficient is probably too small to convert N into mass of product when correcting aNDF.

NDIN - Neutral Detergent Insoluble N (% of N). NDIN is an obsolete acronym that should not be used because it has to be multiplied by 6.25 to convert it to total CP equivalent before it can be used to correct NDF.

NDF - Neutral Detergent Fiber (% of DM). Insoluble fiber residue after extraction for 60 min in neutral detergent solution with sodium sulfite, but not with amylase. This is the original neutral detergent fiber developed by Van Soest and Wine (1967). The original NDF was not corrected for ash in NDF. NDF is often used as a generic term when discussing the general characteristics of insoluble fiber and its impact on ruminant nutrition. See definition of aNDF.

NDR - Neutral Detergent Residue (% of DM). A modification (Van Soest et al., 1991) of the original NDF method that eliminated sodium sulfite and added heat-stable amylase to reduce starch contamination of fiber in cereal silages and grains. The elimination of sodium sulfite resulted in larger values for NDR compared to NDF for heated feeds (see definition for aNDF).

aNDF - amylase-treated Neutral Detergent Fiber (% of DM). Insoluble fiber residue after extraction for 60 min in neutral detergent solution with sodium sulfite and heat-stable amylase (Mertens, 2002). For starch-containing feeds, the results of methods rank: aNDF<NDR<<<NDF. For heated feeds, the results of methods rank:

aNDF<NDF<<<NDR. For most forages, the results of methods rank: aNDF<NDF<NDR, with a 1-2 %-unit difference among methods

aNDFOM (preferred over aNDFom) - amylase-treated Neutral Detergent Fiber Organic Matter (% of DM). This is the organic matter in aNDF that is obtained by subtracting the ash (ash-free aNDF) during the analysis (Mertens, 2002). In clean forage samples, the ash in aNDF is typically 0.5 to 1.5 %-units of DM. The ash in soil is almost 100% insoluble in neutral detergent, and this ash remains in the residue and is measured as aNDF. Soil contaminated samples can have from 2 to 12% aNDF ash, which greatly overestimates the aNDF in these feeds. aNDFOM is the recommended measure of insoluble fiber because it contains no ash and results in a better estimate of NFC. It is also recommended that aNDFOM be blank-corrected because crucibles can lose weight during ashing.

NDS - Neutral Detergent Solubles (% of DM). NDS is the DM that is solubilized by neutral detergent with sulfite, and is calculated by difference: NDS (% of DM) = 100% of DM - [NDF (% of DM)]. For forages fed at 1X maintenance level of intake, NDS digestibility is 0.98 and its endogenous loss is -12.9 % of DM.

aNDS - amylase-treated Neutral Detergent Solubles (% of DM). aNDS is the DM that is solubilized by neutral detergent with sulfite and amylase, and is calculated by difference: aNDS (% of DM) = 100% DM - [aNDF (% of DM)]. For forages fed at 1X maintenance level of intake, aNDS digestibility is probably 0.98 and its endogenous loss is probably close to -12.9 % of DM.

aNDSOM (preferred over aNDSom) - amylase-treated Neutral Detergent Soluble Organic Matter (% of DM). aNDSOM is calculated by difference from OM: aNDS (% of DM) = [OM (% of DM)] - [aNDFOM (% of DM)]; where [OM (% of DM)] = 100% DM - [ash (% of DM)]. For forages fed at 1X maintenance level of intake, aNDSOM digestibility is probably 0.98 and its endogenous loss is probably less than -12.9 % of DM because there is no ash in the endogenous loss.

IVaNDFOMD$_{xx}$ (use instead of IVaNDFOMd) - In Vitro amylase-treated NDF Organic Matter Digestibility where the subscript xx is the time of fermentation [fractional decimal units preferred over (% of aNDFOM)]. This is proportion of aNDF that disappears after xx hours of fermentation. IVaNDFOMDxx = {[aNDFOM (% of DM)] - 100*[(g of IVaNDFOM residue at t=xx / g of DM in the IV sample)]} / [aNDFOM (% of DM)]. The acronyms NDF, NDR, or aNDF should be substituted for aNDFOM in these equations to indicate the exact method used for fiber analysis in the in vitro digestibility results that are reported.

IVdaNDFOM$_{xx}$ (use instead of IVDaNDFOM) - In Vitro digested amylase-treated NDF organic matter measured after xx hours of fermentation (% of DM). The amount of aNDF in DM that disappears after xx hours of fermentation. IVdaNDFOMxx (% of DM) = {[aNDFOM (% of DM)] - 100*[(g of IVaNDFOM residue at xx h) / (g of DM in the IV sample)]}. The acronyms NDF, NDR, or aNDF should be substituted for aNDFOM in these

equations to indicate the exact method used for fiber analysis in the in vitro digestibility results that are reported.

IVuaNDFOM_{xx} (use instead of IVUaNDFOM) - In Vitro undigested amylase-treated NDF Organic Matter measured after xx hours of fermentation (% of DM). This is the amount of aNDF that disappears after xx hours of fermentation. IVuaNDFOMxx (% of DM) = 100*[(g of IVaNDFOM residue at xx h) / (g of DM in the IV sample)]. The acronyms NDF, NDR, or aNDF should be substituted for aNDFOM to indicate the exact method used for fiber analysis in the in vitro digestibility results that are reported. Although time is an important factor in measuring uNDF many other method differences can affect the in vitro result (Mertens et al., 2011).

IVDMD_{xx} (use instead of IVDMd) - In Vitro Dry Matter apparent Digestibility after a fermentation time of xx hours [fractional decimal units preferred over (% of DM)]. The proportion of DM that apparently disappears after xx hours of fermentation. IVDMDxx = {[(g of DM in the IV sample) - (g of IVDM residue after xx h)] / (g of DM in the IV sample)}. This determination is typically generated using the in vitro technique of Tilley and Terry (1963). It can also be generated by the initial fermentation step of the Goering and Van Soest (1970) in vitro technique when residues are dried before neutral detergent extraction. In vitro DM residues must be dried at 60° C or lower, if they are to be extracted with neutral detergent. IVDMDxx is an apparent digestibility because microbial debris will be present in the residues.

IVdDM_{xx} (use instead of IVDDM) - In Vitro apparently digested Dry Matter after a fermentation time of xx hours (% of DM. Dry Matter is the only component in which IVdDM = IVDMD(fractional decimal)*100. IVDMD is the preferred acronym.

IVDMTD_{xx} (use instead of IVTDMD) - In Vitro Dry Matter True Digestibility after a fermentation time of xx hours [fractional decimal units preferred over (% of DM)]. The proportion of DM that truly disappears after xx hours of fermentation by removing microbial debris using neutral detergent as described by the 2-step method (i.e., fermentation and extraction) of Goering and Van Soest (1970). IVDMTDxx = [(g of DM in the IV sample) - (g of IVaNDF residue after xx h)] / (g of DM in the IV sample). IVDMTD will always be larger than IVDMD because the IVaNDF residue is smaller than the IVDM residue, which contains microbial debris.

IVtdDM_{xx} (use instead of IVTDDM) - In Vitro truly digested Dry Matter after a fermentation time of xx hours. Dry Matter is the only component in which IVtdDM = IVDMTD (fractional decimal)*100. IVDMTD is the preferred acronym.

IVOMD_{xx} (use instead of IVOMd) - In Vitro Organic Matter apparent Digestibility after a fermentation time of xx hours [fractional decimal units preferred over (% of OM)]. The proportion of OM that apparently disappears after xx hours of fermentation. IVOMDxx = [(g of OM in the IV sample) - (g of IVOM residue after xx h)] / (g of OM in the IV sample). IVOMD is typically generated using the Tilley and Terry (1963) in vitro technique. It can also be generated by the initial fermentation step of the Goering and Van Soest (1970) in

vitro technique when residues are dried and ashed. IVOMD is an apparent digestibility because microbial debris is present in the IV residues.

IVdOMxx (use instead of IVDOM) - In Vitro apparently <u>digested</u> Organic Matter after a fermentation time of xx hours (% of DM). The amount of OM in DM that disappears after xx hours of fermentation. IVdOMxx (% of DM) = {[OM (% of DM)] - 100*[(g of IVOM residue at xx h) / (g of DM in the IV sample)]}. It is typically generated using the Tilley & Terry (1963) in vitro technique. It can also be generated by the Georing and Van Soest (1970) in vitro technique when residues of the initial fermentation step are dried and ashed. IVOMD is an apparent digestibility because microbial OM debris will be present in the residues. IVdOM <u>is similar</u> to the "d" or "D" value typically reported by European laboratories.

IVOMTDxx (use instead of IVTOMD) - In Vitro Organic Matter True Digestibility after a fermentation time of xx hours [fractional decimal units preferred over (% of OM)]. The proportion of DM that truly disappears after xx hours of fermentation by removing microbial debris using neutral detergent as described by the 2-step method (i.e., fermentation and extraction) of Goering and Van Soest (1970) and IV residues are ashed. IVOMTDxx = [(g of OM in the IV sample) - (g of IVaNDFOM residue after xx h)] / (g of OM in the IV sample). IVOMTD will always be larger than IVOMD because the IVaNDFOM residue is smaller than the IVOM residue, which contains microbial debris.

IVtdOMxx (use instead of IVTDOM) - In Vitro <u>truly digested Organic Matter</u> measured after xx hours of fermentation (% of DM). The amount of OM in DM that disappears after xx hours of fermentation. IVtdOMxx (% of DM) = {[OM (% of DM)] - [100*(g of IVaNDFOM residue at xx h) / (g of DM in the IV sample)]}. IVaNDFOM residue is generated using the 2-step in vitro method of Goering and Van Soest (1970).

iNDF (use instead of INDF or NDFI) - indigestible NDF (% of DM). The kinetic model parameter (pool or compartment) of NDF that is not digestible after infinite time of fermentation. It is estimated by, but not equal to, uNDF measured at long fermentation times, and the time of fermentation for estimating iNDF can vary with the model. iNDF is the generic term that should be used when discussing the biological or model concept and uNDF should refer only to the measurement.

iNDFOM - indigestible NDF Organic Matter (% of DM). This is probably the preferred modeling or biological entity because it removes any intrinsic ash or soil contamination that should not be a part of fermentative digestion.

Space does not allow the definition of other variables. Note that nonfibrous carbohydrates (NFC) will vary with the NDF measured and its correction for protein or ash contamination. Each of these NFC should have different acronyms to denote the differences in their calculation. Additional kinetic terminology can be found in Mertens (2005).

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