NDF Digestibility and uNDF: What does this mean and how can we apply it to make better decisions

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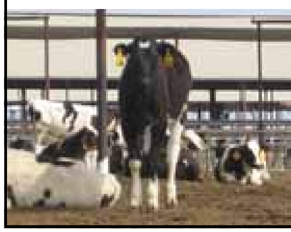


Dept. of Animal Science

Chazy, NY

Outline

- aNDFom – why and what it means
- aNDFom digestibility
- uNDF – definition
- uNDF and NDF pools
- Implications of using this approach
- Summary

NDF analyses

- Nutrition models/software have an input for NDF that is used primarily to calculate energy from available carbohydrates and effective fiber
- Mertens (2002) published the NDF method and gained AOAC approval – there are many approaches to measure NDF
- We want everyone to use of aNDFom – NDF with sulfite and ash correction – we are working to move labs in that direction
- Sniffen et al. 1992…

Why aNDFom?

- Hay in a hurry – wide swathing picks up dirt
- 600-800 hp choppers and big equipment that move fast make dust and dirt fly
- Flood irrigation moves soil
- Dirt/soil does not solubilize in NDF solution, thus if not corrected will inflate the NDF content
- Inflation of the NDF content means the diet as formulated is lower in actual NDF – intake and rumen health can be compromised

27 FIELD 316 SORGHUM X SUDAN

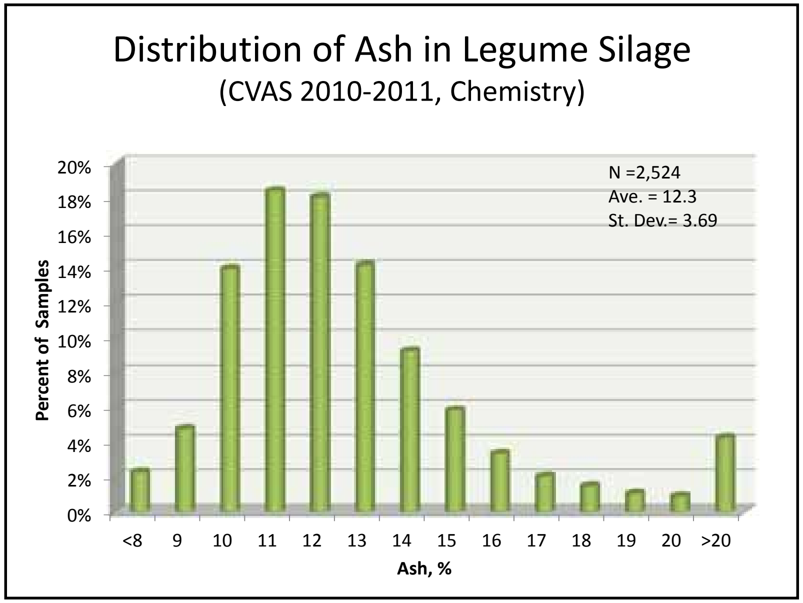
FIBER	% NDF	% DM
ADF	56.5	34.0
aNDF	→	60.2
aNDFom	→	55.4
NDR (NDF w/o sulfite)		
peNDF		
Crude Fiber		
Lignin	4.95	2.98
NDF Digestibility (12 hr)		
NDF Digestibility (24 hr)		
NDF Digestibility (30 hr)	60.2	36.3
NDF Digestibility (48 hr)		
NDF Digestibility (240 hr)	74.9	45.1
uNDF (30 hr)	39.8	24.0
uNDF (240 hr)	25.1	15.1

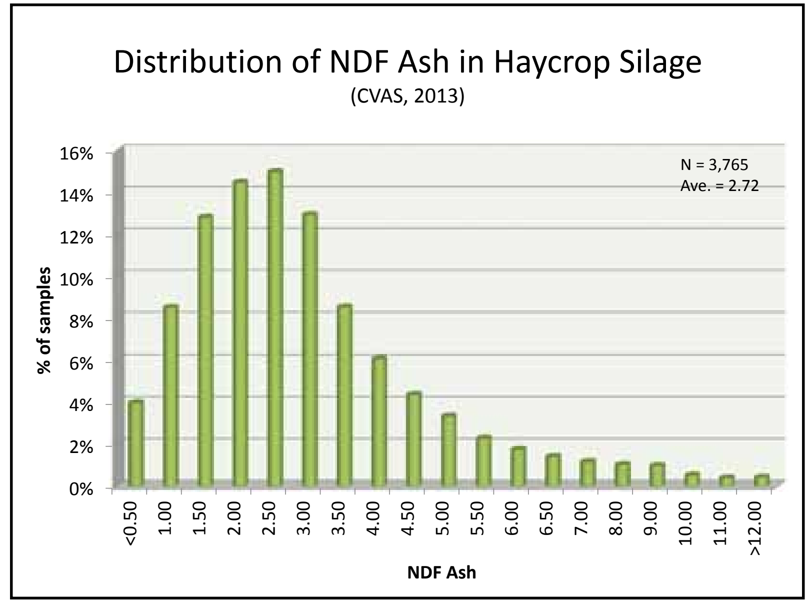
~ 5 units

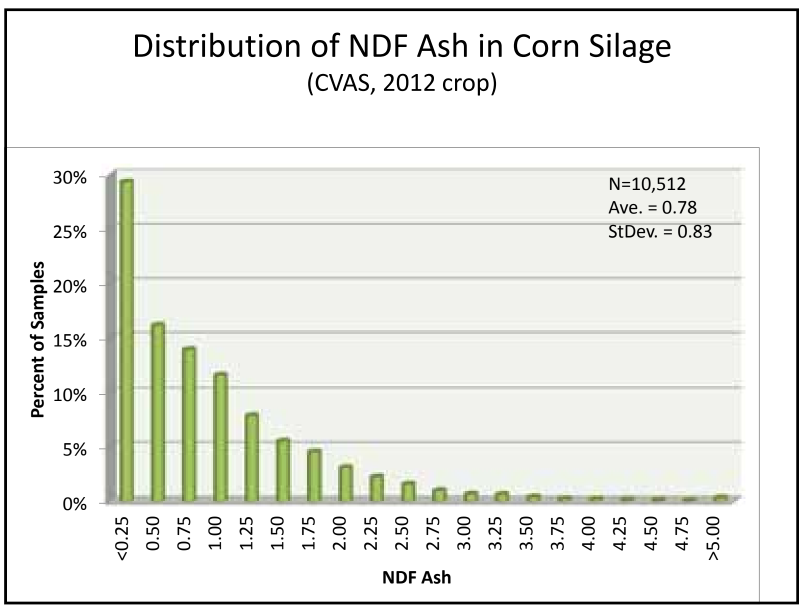
26 FIELD 308 TEST 2 SORGHUM X SUDAN

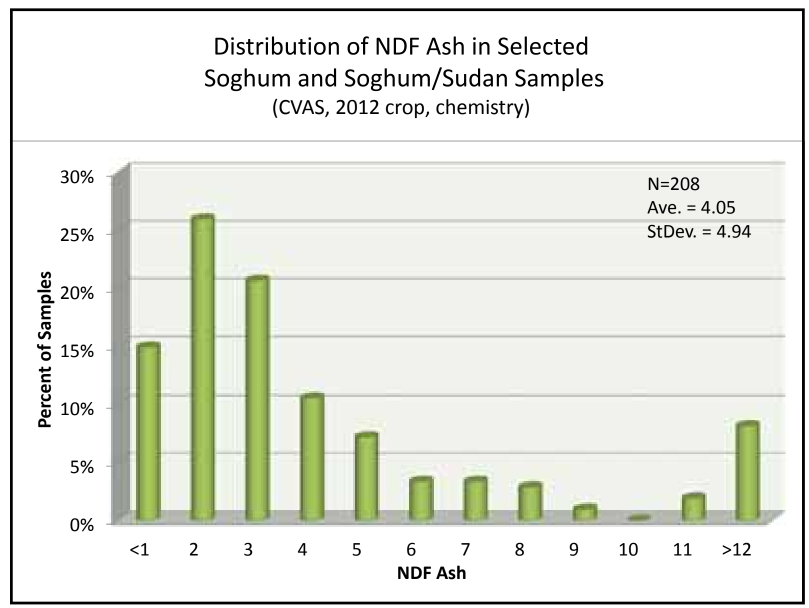
FIBER	% NDF	% DM
ADF	57.6	36.8
aNDF	→	63.9
aNDFom	→	53.7
NDR (NDF w/o sulfite)		
peNDF		
Crude Fiber		
Lignin	4.86	3.11
NDF Digestibility (12 hr)		
NDF Digestibility (24 hr)		
NDF Digestibility (30 hr)	49.3	31.5
NDF Digestibility (48 hr)		
NDF Digestibility (240 hr)	77.0	49.2
uNDF (30 hr)	50.7	32.4
uNDF (240 hr)	23.0	14.7

10 units


Distribution of Ash in Legume Silage
(CVAS 2010-2011, Chemistry)
N =2,524
Ave. = 12.3
St. Dev.= 3.69
Percent of Samples
Ash, %
<8 9 10 11 12 13 14 15 16 17 18 19 20 >20


Distribution of NDF Ash in Haycrop Silage
(CVAS, 2013)
N = 3,765
Ave. = 2.72
% of samples
NDF Ash


Distribution of NDF Ash in Corn Silage
(CVAS, 2012 crop)
N=10,512
Ave. = 0.78
StDev. = 0.83
Percent of Samples
NDF Ash


Distribution of NDF Ash in Selected
Soghum and Soghum/Sudan Samples
(CVAS, 2012 crop, chemistry)
N=208
Ave. = 4.05
StDev. = 4.94
Percent of Samples
NDF Ash
<1 2 3 4 5 6 7 8 9 10 11 >12

Example of the Impact of Ash Contamination on NDF and NDF Digestibility Recovery

Sample	NDF	NDFom	NDFD30	NDFD30om
15081-068	54.6%		56.3%	

Ralph Ward

Example of the Impact of Ash Contamination on NDF and NDF Digestibility Recovery

Sample	NDF	NDFom	NDFD30	NDFD30om
15081-068	54.6%	**48.3%**	56.3%	**65.9%**

Ralph Ward

Example of the Impact of Ash Contamination on NDF and NDF Digestibility Recovery

Sample	NDF	NDFom	NDFD30	NDFD30om
15081-68	54.6%	**48.3%**	56.3%	**65.9%**
15085-56	60.1%		49.7%	

Ralph Ward

Example of the Impact of Ash Contamination on NDF and NDF Digestibility Recovery

Sample	NDF	NDFom	NDFD30	NDFD30om
15081-68	54.6%	**48.3%**	56.3%	**65.9%**
15085-56	60.1%	**50.9%**	49.7%	**61.9%**

Ralph Ward

Fiber degradation and iNDF

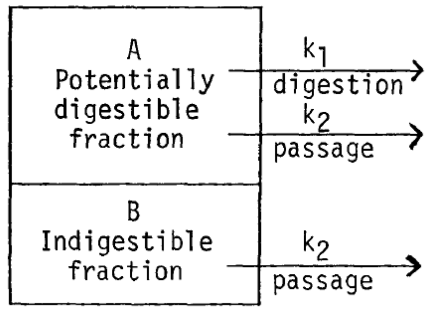


FIG. 1. Rumen cellulose split into two fractions—potentially digestible which disappear by digestion and passage and indigestible which disappears by passage.

Adapted from Waldo et al., 1972

How do we currently characterize NDF indigestibility? (iNDF)

Models like the CNCPS use (2.4 x lignin)/NDF

Dairy NRC (2001) and forage labs based on Weiss et al., 1992 use $(\text{lignin/NDF})^{0.67}$

Van Soest and Lane Moore, 1963
USDA, Beltsville, MD right after
Pete characterized NDF

Nomenclature slide - iNDF vs uNDF

Literature uses the term iNDF for indigestible NDF

We have an "Informal Fiber Working Group" that meets at least once per year around the Cornell Nutrition Conf. (Cornell, Miner Institute, Univ. of Bologna, Nutreco, ADM, Univ. of Parma, most commercial labs, Charlie Sniffen, Dave Mertens)

Mertens proposed a change in name from iNDF to uNDF –

> the NDF we call iNDF can digest, just not under anaerobic conditions, so to say indigestible is a misrepresentation – so we now use uNDF – undigested NDF

NDF Digestibility/Indigestibility

- Nousiainen et al. (2003; 2004)
  demonstrated in grasses that the relationship between lignin and digestibility was highly variable
- This was confirmed by Rinne et al. 2006 on legumes
  – methods used to determine this included 288 hr in situ (in a bag in the rumen) fermentations
- We were/are doing similar work at Cornell
  - Working to develop a procedure that could be used in a commercial lab
    Ph.D. work of Raffrenato (2011)

Corn Silage NDF Digestibility by NDF and Lignin Content

NDF, %DM	Lignin, %DM
42.3	3.01
42.6	3.32
42.6	3.24
42.6	3.24
42.3	3.18
42.3	3.00

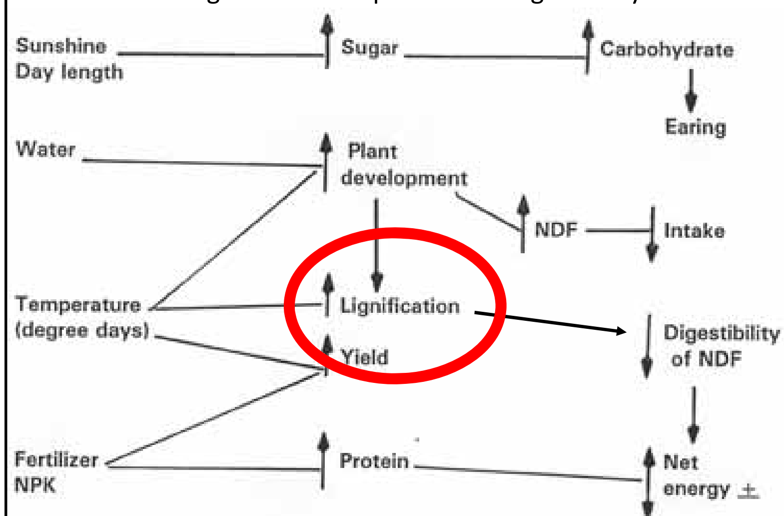
Corn Silage NDF Digestibility by NDF and Lignin Content

NDF, %DM	Lignin, %DM	NDFD% (30hr)	Est. NDF kd, %h
42.3	3.01	42.2	2.63
42.6	3.32	44.1	2.90
42.6	3.24	44.6	2.92
42.6	3.24	50.8	3.60
42.3	3.18	56.7	4.36
42.3	3.00	57.0	4.30

"Lignification" = cross linking between lignin and hemicellulose

- Light, heat and water interact at various stages of development
- For example, water stress causes greater cross-linking between lignin and hemicellulose
- Similar to the effect of building a very tall building

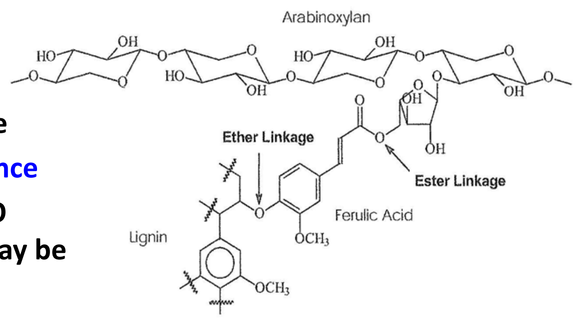
Factors Affecting Plant Development and Digestibility



From Van Soest, 1996

Lignin – Phenolic Acid – Hemicellulose Linkage

- Ester & ether linkages to hemicellulose
- Steric hindrance
- Phenolic-CHO complexes may be toxic



(Grabber, 2005)

Ratio of lignin to uNDF

Group	n	NDF	ADL	uNDF	Ratio (range)
		%DM	g/kg NDF		uNDF/ADL (%NDF)
Conventional C.S.	30	42.7	72.4	316.8	4.72 (1.73-7.59)
BMR C.S.	15	39.1	43.6	171.7	4.01 (3.14-5.45)
Grasses	15	47.2	62.1	222.8	3.63 (2.51-4.73)
Mature grasses	11	64.5	84.4	313.8	3.89 (2.60-5.64)
Immature grasses	13	44.1	59.3	232.2	4.16 (2.59-7.40)
Alfalfas	18	36.6	172.6	461.4	2.70 (2.43-2.95)

Raffrenato 2011

NDF Digestibility/Indigestibility

Weisbjerg et al. (2010) measured iNDF in legumes and grasses

- 288 h in situ,
- 12 µm porosity bags

Grasses range between 1.27-4.57 for ADL and iNDF

Legumes ranged between of 1.22-3.59 for ADL and iNDF respectively,

Corn silage example for uNDF 240 vs lignin*2.4 – 2013 corn silages

	CS 1	CS 2	CS 3	CS 4
NDF, %DM	45.4	44.5	40.3	50.2
aNDFom, %DM	44.4	43.8	38.8	49.3
Lignin, %DM	3.40	3.43	2.87	4.26
Lignin*2.4/NDF	18.4	18.7	17.9	20.7
uNDF, %NDF	11.8	10.7	10.9	14.2

Corn silage chemistry and uNDF by three methods, 240 hr uNDF, Chandler et al. (1980) and Conrad et al., 1984 equations

Corn silage	aNDF, %DM	aNDFom, %DM	uNDF, %NDF	Chandler et al. 1980	Conrad et al., 1984
1	38.1	37.5	23.6	42.3	16.4
2	39.5	38.9	25.6	39.2	16.9
3	41.5	40.9	27.3	43.4	17.7
4	43.7	41.9	22.8	42.8	31.8

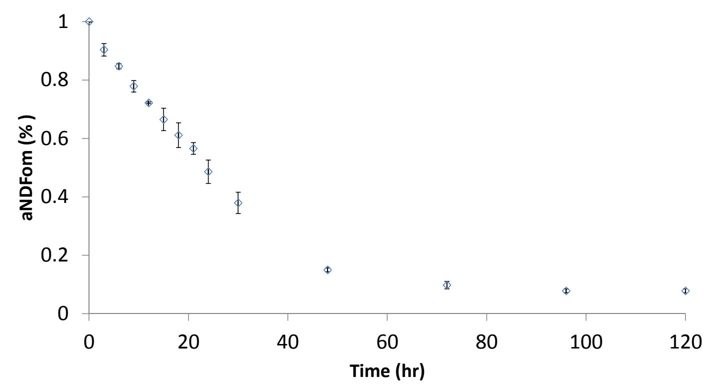
Opportunity with uNDF

- Improve predictions of energy from forages – more biologically appropriate measurement
- Eliminate the need for ADF and lignin measurements
  - Only do ADF to get to lignin
  - Only use lignin to calculate relationships to NDF (either CNCPS approach or Weiss et al 1992)
- Helps improve predictions of intake and rumen function – microbial production, etc

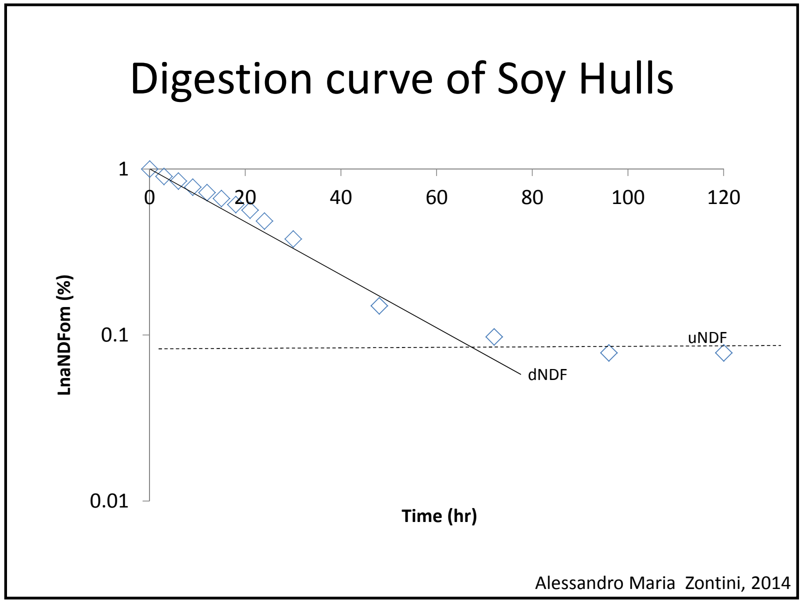
What about Non-forage Fiber Feeds?

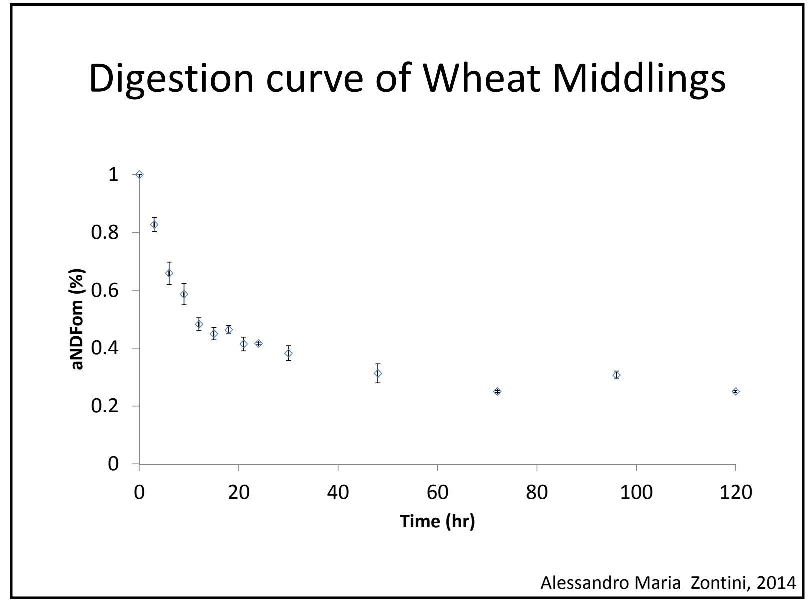
- Do they have the same digestion behavior as forages?
- What are the time-points?

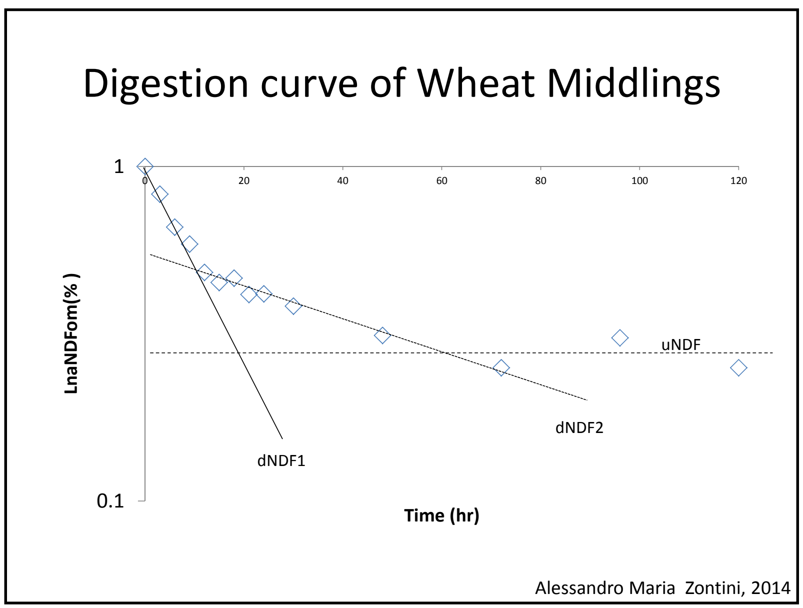
Digestion curve of Soy Hulls

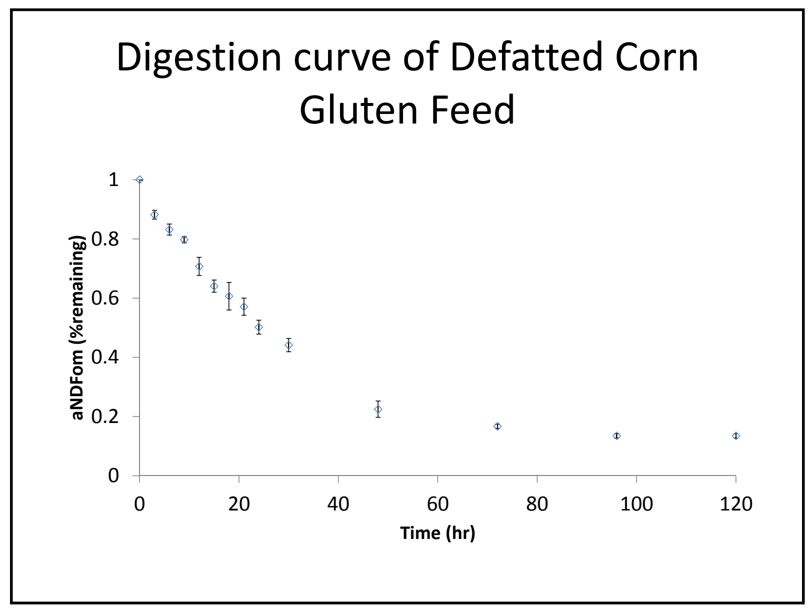


Alessandro Maria Zontini, 2014

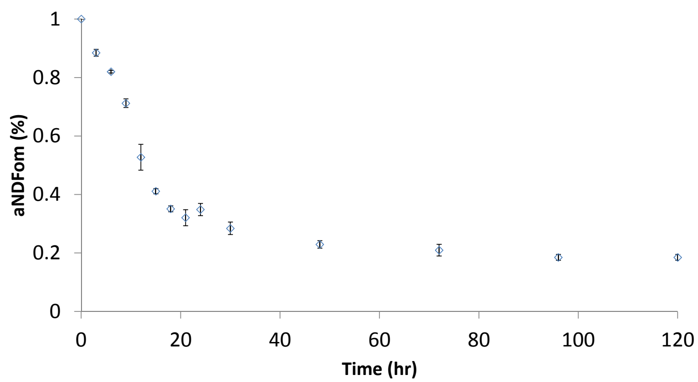

Digestion curve of Soy Hulls
1
0.1
0.01
0
20
40
60
80
100
120
LnaNDFom (%)
uNDF
dNDF
Time (hr)
Alessandro Maria Zontini, 2014


Digestion curve of Wheat Middlings
1
0.8
0.6
0.4
0.2
0
aNDFom (%)
0
20
40
60
80
100
120
Time (hr)
Alessandro Maria Zontini, 2014


Digestion curve of Wheat Middlings
1
0.1
0
20
40
60
80
100
120
LnaNDFom(%)
uNDF
dNDF2
dNDF1
Time (hr)
Alessandro Maria Zontini, 2014


Digestion curve of Defatted Corn Gluten Feed
1
0.8
0.6
0.4
0.2
0
aNDFom (%remaining)
0
20
40
60
80
100
120
Time (hr)

Beet Pulp



Degradation behavior

Feed	1 dNDF	2 dNDF
Beet Pulp	x	
Canola Meal	x	
Citrus Pulp	x	
Corn Gluten Feed	x	
Corn Distiller	x	
Corn Germ	x	
Flaked Corn	x	
Rice Hulls	x	
Soy Plus	x	
Soy Hulls	x	
Wheat Distiller	x	
Wheat Midds		x

Observations

1) uNDF is best estimated at 120 of in vitro fermentation

2) Non-forages feeds are best characterized using a two pools model (dNDF + uNDF)

Which time points are most appropriate to estimate the decay?

Selecting time-points

TP/|1-Slope|	24-48-96	15-48-96	15-48-72	12-48-72	9-48-96	12-72-96	12-72-120	12-48-120
Beet Pulp	0.0477	0.0418	0.0676	0.0731	0.0962	0.0459	0.0510	0.0443
Canola Meal	0.0002	0.0099	0.0699	0.0709	0.0023	0.0479	0.0492	0.0706
Citrus	0.0036	0.0247	0.0130	0.0068	0.0420	0.0074	0.0076	0.0593
Corn Gluten	0.0672	0.0315	0.0810	0.0810	0.0315	0.0315	0.0122	0.0595
Corn Distiller	0.0748	0.0649	0.0729	0.0827	0.0868	0.0578	0.0538	0.0695
Corn Germ	0.0335	0.0334	0.0505	0.0722	0.0943	0.0786	0.0786	0.1096
Rice Hulls	0.2391	0.1962	0.1545	0.1384	0.1850	0.1621	0.1227	0.1469
Soy Bean Meal	0.0428	0.0454	0.0442	0.0398	0.0548	0.0705	0.0661	0.0351
Soy Hulls	0.0643	0.0825	0.0843	0.0655	0.0789	0.0566	0.0605	0.0544
Soy Plus	0.0818	0.0555	0.1089	0.1113	0.0555	0.0805	0.0579	0.0391
Wheat Distiller	0.0137	0.0343	0.0626	0.0554	0.0030	0.0342	0.0356	0.0259
Wheat Midds	0.0677	0.0398	0.0333	0.1162	0.0690	0.0115	0.0132	0.0885
Average	0.0614	0.0550	0.0702	0.0761	0.0666	0.0570	0.0507	0.0669
STD	0.0625	0.0483	0.0365	0.0350	0.0491	0.0406	0.0321	0.0343

Selecting time-points

TP/Intercept	24-48-96	15-48-96	15-48-72	12-48-72	9-48-96	12-72-96	12-72-120	12-48-120
Beet Pulp	0.033	0.004	0.012	0.042	0.092	0.023	0.027	0.022
Canola Meal	0.040	0.049	0.047	0.038	0.086	0.023	0.026	0.038
Citrus	0.021	0.001	0.017	0.000	0.054	0.018	0.016	0.009
Corn Gluten	0.037	0.028	0.039	0.028	0.035	0.033	0.026	0.022
Corn Distiller	0.039	0.031	0.032	0.032	0.064	0.018	0.015	0.027
Corn Germ	0.020	0.101	0.004	0.133	0.201	0.080	0.072	0.094
Rice Hulls	0.242	0.192	0.153	0.128	0.177	0.151	0.111	0.138
Soy Bean Meal	0.024	0.002	0.006	0.030	0.011	0.014	0.017	0.036
Soy Hulls	0.022	0.026	0.035	0.049	0.023	0.035	0.033	0.031
Soy Plus	0.050	0.010	0.042	0.033	0.024	0.013	0.004	0.012
Wheat Distiller	0.023	0.062	0.075	0.043	0.025	0.045	0.047	0.006
Wheat Midds	0.044	0.040	0.009	0.012	0.038	0.034	0.036	0.022
Average	0.050	0.045	0.039	0.047	0.069	0.041	0.036	0.038
STD	0.061	0.054	0.041	0.041	0.061	0.039	0.029	0.039

uNDF of Non-forage Fiber Sources

1) uNDF is best estimated at 120 of in vitro fermentation
2) Concentrates feeds are best characterized using a two pools model (dNDF + uNDF)
3) 0, 12, 72, and 120h are the time points to use for non-forage feeds

Comparison of three methods of estimation of uNDF - 120 hr fermentation, Chandler equation and the Conrad equation

Feed	aNDFom (%DM)	uNDF (%aNDFom)	2.4 x ADL (%aNDFom)	$ADL^{2/3}/NDF^{2/3}$ (%aNDFom)
Beet pulp	47	19	28	24
Canola meal	29	41	73	45
Citrus pulp	25	20	19	53
Corn gluten feed	37	14	15	4
Corn distiller	41	16	26	23
Corn germ	63	29	23	21
Flaked corn	13	14	26	23
Soybean meal	9	1	23	21
Soy hulls	72	9	10	7
Wheat distillers	38	26	29	22
Wheat middlings	45	31	17	23

uNDF Study @ Miner Institute

- What does it mean and how do we take advantage of the information?

Composition of diets used in uNDF study at Miner Institute.

	Diet			
Ingredient % of ration DM	LF-LD (Low CS)	HF-LD (High CS)	LF-HD (Low BMR)	HF-HD (High BMR)
Conventional corn silage	39.2	54.9	---	---
Brown midrib corn silage	---	---	36.1	50.2
Hay crop silage	13.4	13.4	13.3	13.3
Corn meal	17.3	1.6	20.4	6.3
Grain mix	30.1	30.1	30.2	30.2
Chemical composition				
Crude protein, % of DM	17.0	17.0	16.7	16.7
NDF,% of DM	32.1	35.6	31.5	35.1
Starch, % of DM	28.0	21.2	27.8	23.8
24-h NDF digestibility, %	56.3	54.0	62.0	60.3
peNDF, % of DM	17.3	23.1	18.5	21.5

uNDF study – Miner Inst.

	High CCS	Low CCS	High BMR	Low BMR
DMI lb/d	58.43	63.95	64.39	64.61
SCM lb/d	92.17	99.67	100.77	102.31
Efficiency	1.58	1.56	1.57	1.58

uNDF Intake, Rumen content and Fecal excretion

	High CCS	Low CCS	High BMR	Low BMR
uNDF Intake lb/d	5.80	5.27	4.87	4.48
uNDF Rumen lb	9.17	8.42	7.63	7.06
uNDF Fecal lb /d	5.80	5.27	4.87	4.48

Can we use this to better predict DMI?

	High CCS	Low CCS	High BMR	Low BMR
uNDF, %DM	9.92%	8.24%	7.57%	6.93%
uNDFi : uNDFf	1.00	1.00	1.00	1.00
uNDFi : uNDFr	0.63	0.63	0.64	0.63

uNDFi, uNDF Intake
uNDFf, uNDF Fecal
uNDFr, uNDF Rumen content

Interpretation

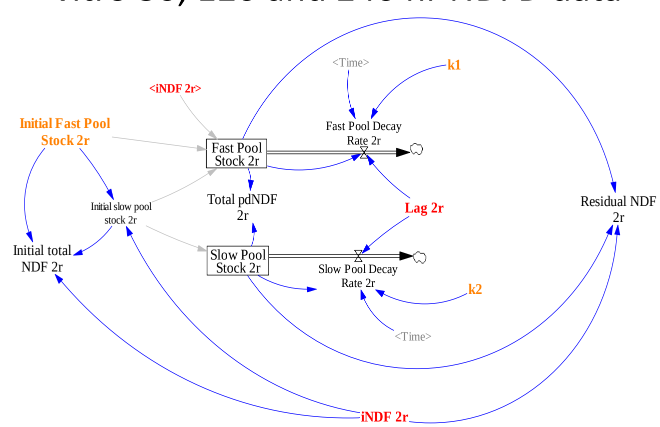
- Need to understand what changes uNDF Rumen content
  - 4.48 – 5.80 lbs. or 7% - 10% DMI is significant
  - Rumen content appears to determine intake and fecal output of uNDF
  - What causes variation of uNDF Rumen content?
- "Working hypothesis": the disappearance of the fast and slow pools of pdNDF determines volume of uNDF Rumen content and capacity along with the "ballast and rumen fill of the slow and uNDF fractions.

Perspective

	High CCS	Low CCS	High BMR	Low BMR	Median
uNDF, %DM	9.92%	8.24%	7.57%	6.93%	**7.90%**
uNDF Intake lb	5.80	5.27	4.87	4.48	**5.07**
uNDF Rumen, lb	9.17	8.42	7.63	7.06	**8.03**
uNDF Fecal/d	5.80	5.27	4.87	4.48	**5.07**
uNDFi:uNDFf	1.00	1.00	1.00	1.00	**1.00**
uNDFi:uNDFr	0.63	0.63	0.64	0.63	**0.63**

Take into account current uNDF% and intake while rebalancing diet. If you know current capacity based on current feeds you should be able to optimize better diet.

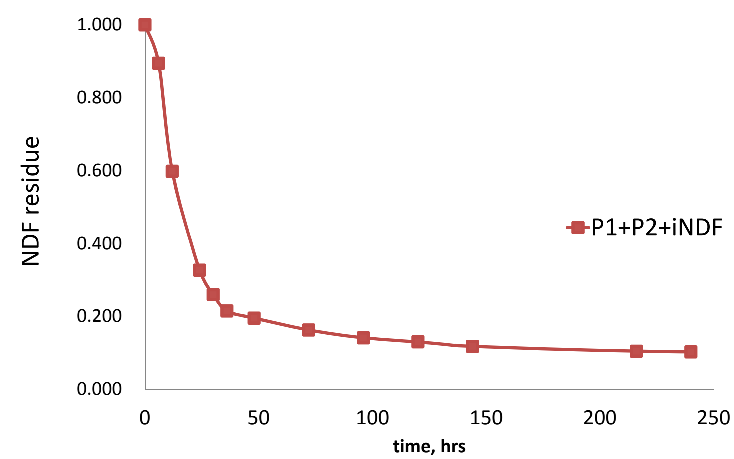
Calculation of rates and pool sizes using in-vitro 30, 120 and 240 hr NDFD data



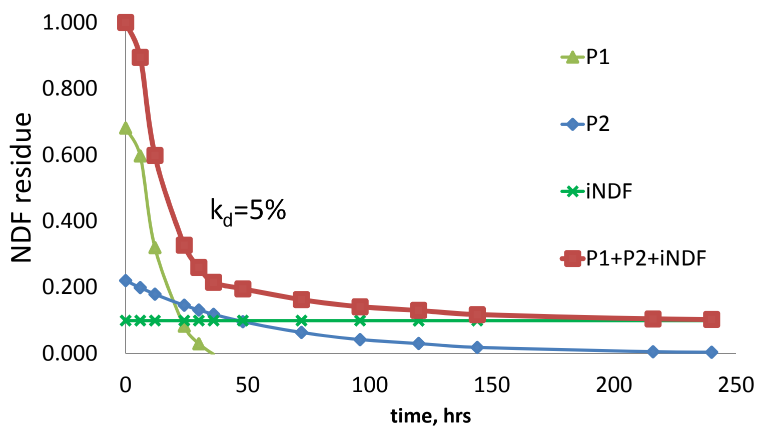
Parameters in orange are the those to be optimized

Raffrenato et al. 2011

Corn silage example: $NDF_{digestibility}$

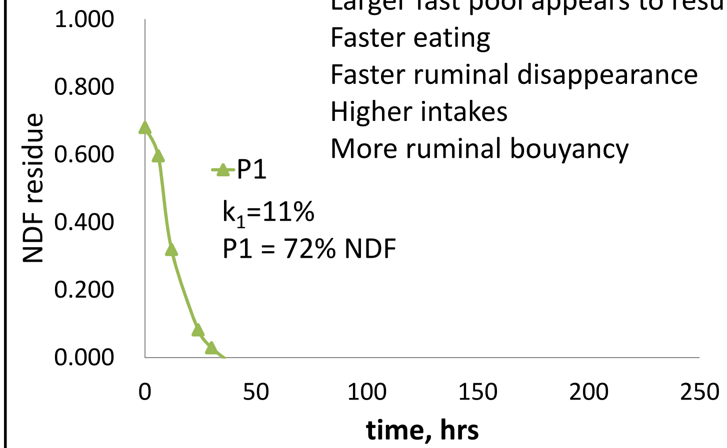


Corn silage example: P1+P2+iNDF



Corn silage example: fast pool

Larger fast pool appears to result in:
Faster eating
Faster ruminal disappearance
Higher intakes
More ruminal bouyancy

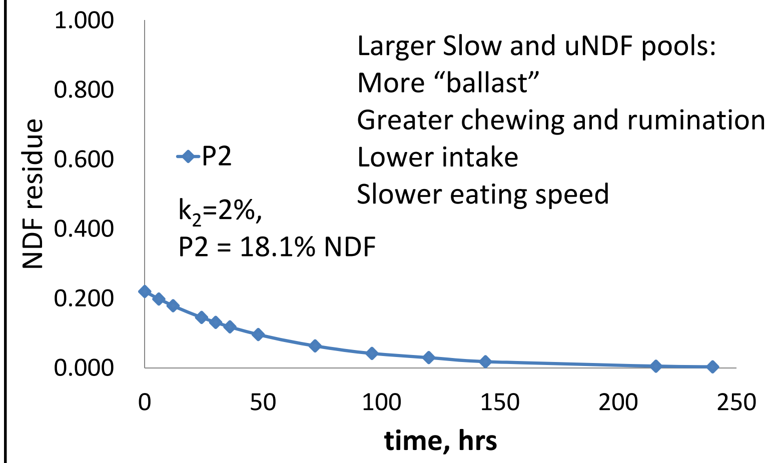


Undigested NDF residues of CS, Grass silage and Hay Busted Straw 47h in situ followed by washing machine and NDF processing in Ankom 10x20 dacron bags using Ankom fiber analyzer
Miner 2014

Corn silage uNDF residue after 47h in situ, laundered and NDF assay

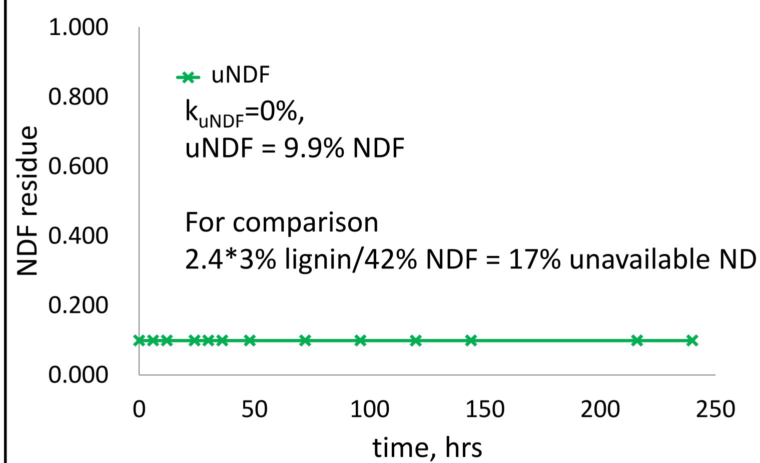
Grass silage uNDF residue after 47h in situ, laundered and NDF assay

Corn silage example: slow pool

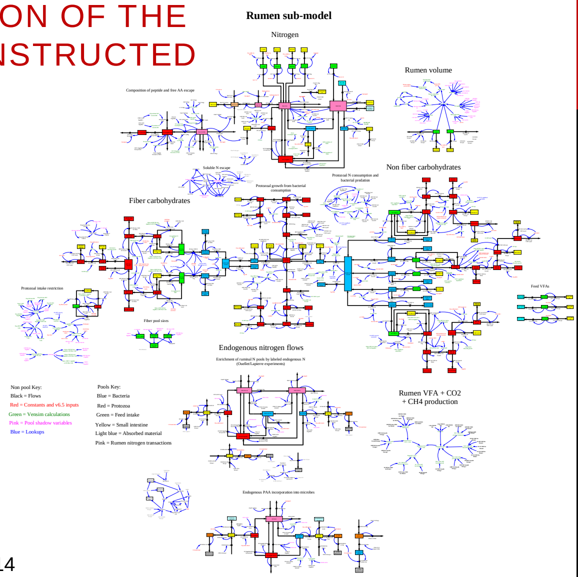


Straw (HB) uNDF residue after 47h in situ, laundered and NDF assay

Corn silage example: iNDF



NEW VERSION OF THE CNCPS CONSTRUCTED IN VENSIM



Ryan Higgs, Ph.D. 2014

Application of a technology to improve NDF digestibility

Ingredients	lb DM	% Diet
Corn Silage Processed 35 DM 49 NDF		
Medium	22.9	38.8%
Alfalfa Silage 17 CP 46 NDF 20 LNDF	11.5	19.4%
Corn Grain Ground Fine	15.4	26.1%
Soybean Meal 47.5 Solvent	0.0	0.0%
Soy Pass	4.4	7.5%
Blood Meal Average	1.5	2.5%
Energy Booster 100	1.0	1.7%
MinVit	2.2	3.7%
Urea	0.1	0.2%
Total	58.9	100%

Chemical composition of the diets

Crude protein, %DM	**15.6**
SolP (% CP)	**39.5**
Ammonia (% SP)	**8.5**
ADIP (% CP)	**6.7**
NDIP (% CP)	**15.7**
%NFC	**36.4**
Sugars	**2.4**
Starch	**27.2**
NDF	**35.4**
peNDF	**55.8**
Lignin (% NDF)	**10.0**
Ether extract	**4.7**
Ash	**8.2**
Forage % DM	**58.3**

Chemical analyses of the control and treatment forages using the three pool approach for NDF

Feed name	Fast Pool NDF (% NDF)	Slow Pool NDF (% NDF)	uNDF (%NDF)	kd 1 (%/hr)	kd 2 (%/hr)
Control corn silage	54.2	27.2	18.6	9.7	1.4
Treatment corn silage	62.5	25.3	12.2	6.1	1.9
Control alfalfa silage	32.3	29.4	38.3	5.2	1.5
Treatment alfalfa silage	50.5	12.4	37.1	9.0	1.8

Predicted rumen pools sizes and expected DM intake – g/d

	Control	Control lower intake	Technology treatment
B3 Fast CHO	1849	1624	2578
B3 Slow CHO	3082	2732	2174
C CHO	5082	4587	4203
Total rumen NDF	10013	8943	8955
DMI (lbs)	59.1	51.4	59.1

Dry matter intake on the control example was reduced to a level where the total rumen NDF pool was equivalent to the treatment example (indicated in red). Based on this example intake might be expected to be different by 7.7 lbs. The diet modeled is high forage and high NDF and probably represents the situation with the greatest opportunity to achieve an intake response.

Conclusions and implications

- The use of 240 hr NDFD better describes the undigestibility of the forage for use in cattle
- A better description of NDF undigestibility can be implemented by commercial laboratories – especially for undigested NDF – will have to build new NIR calibrations
- Working to develop a larger data set to explain the variation in NDF pool sizes and rates for all NDF containing feeds
  - Within forage group information is linked to agronomic and environmental conditions but not well described

Opportunity with uNDF

- Improve predictions of energy from forages – more biologically appropriate measurement
- Eliminate the need for ADF and lignin measurements
  - Only do ADF to get to lignin
  - Only use lignin to calculate relationships to NDF (either CNCPS approach or Weiss et al 1992)
- Helps improve predictions of intake and rumen function – microbial production, etc

Thank you for your attention.

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