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Physically effective fiber: influence of fiber source, chemistry, and structure

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20th Annual Dairy Cattle Nutrition Workshop
Post-conference Seminar
November 6, 2019
4:55 - 5:20
Hershey Lodge, Hershey, PA

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NRC, 2001 Carbohydrate Recommendations

TABLE 4-3 Recommended Minimum Concentrations (% of DM) of Total and Forage NDF and Recommended Maximum Concentrations (% of DM) of NFC for Diets of Lactating Cows When the Diet is Fed as a Total Mixed Ration, the Forage has Adequate Particle Size, and Ground Corn is the Predominant Starch Source[a]

Minimum forage NDF[b]	Minimum dietary NDF	Maximum dietary NFC[c]	Minimum dietary ADF[d]
19[e]	25[e]	44[e]	17[e]
18	27	42	18
17	29	40	19
16	31	38	20
15[e]	33	36	21

[a]Values in this table are based on the assumption that actual feed composition has been measured; values may not be appropriate when values from feed tables are used.
[b]All feeds that contain substantial amounts of vegetative matter are considered forage. For example, corn silage is considered a forage, although it contains significant amounts of grain.
[c]Nonfiber carbohydrate is calculated by difference 100 - (%NDF + %CP + %Fat + %Ash).
[d]Minimum dietary ADF recommendations were calculated from NDF concentrations (See text).
[e]Diets that contain less fiber (forage NDF, total NDF or total ADF) than these minimum values and more NFC than 44 percent should not be fed.

"Quantitative measures of particle size (i.e., mean particle size, mean standard deviation and/or distribution) rather than qualitative descriptions (e.g., coarsely chopped) are needed to improve the accuracy of assessing fiber requirements of dairy cows"

"At the present time, the lack of standard, validated methods to measure effective fiber of feeds or to establish requirements for effective fiber limits the application of this concept."

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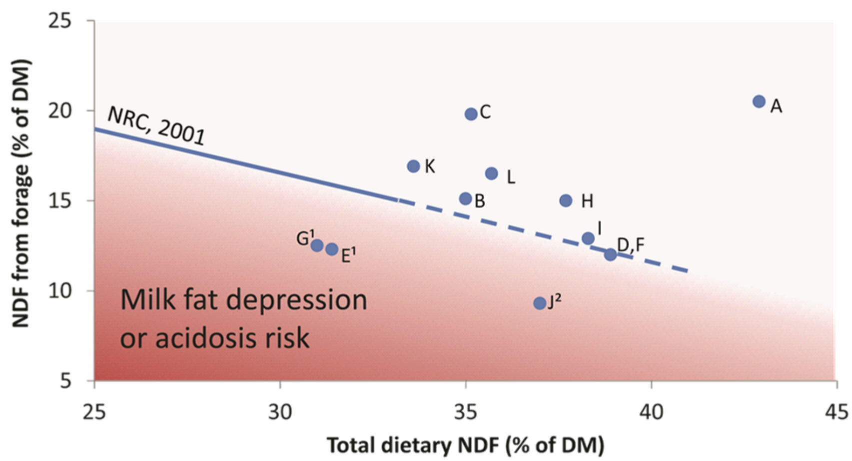
Nonforage sources replacing some forage: Diets that decreased pH (1) or milk fat (2) are denoted with a superscript



Bradford and Mullins, 2012

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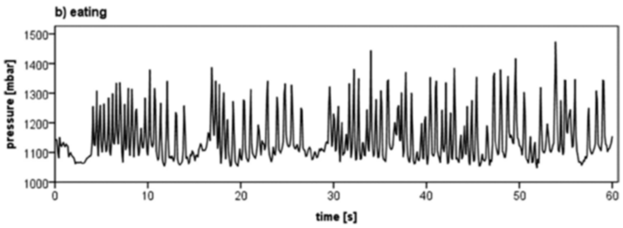
Eating Activity



Zehner et al., 2017

- prehension of feed by the mouth, followed by chewing and swallowing of the boli (Beauchemin, 1991).
- 284 min/d (range: 141 – 507 min/d) (White et al., 2017a).
- heterogeneous with irregular interruptions and unsteady frequencies (Zehner et al., 2017).
- Affected by *availability*, *% forage*, *chemical composition* and *physical processing* of the diet (Albright, 1993; Susenbeth et al., 1998).

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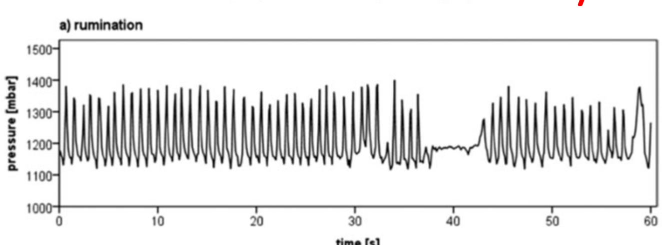
Rumination Activity



Zehner et al., 2017

- Quiet and relaxed state of awareness and often exhibited when animals are lying down with their heads and eyelids lowered (Albright and Arave, 1997).
- 436 min/d (range: 236 – 610 min/d) (White et al., 2017a).
- > 30 movements, > 3 min in duration (Zegner et al., 2017)
- Cyclical process of ingesta, remastication, and reswallowing (Beauchemin, 1991).
- Upon reaching the mouth, a small portion of liquid and small particles contained in the bolus are reswallowed, whereas the remaining bolus material is remasticated and *mixed with saliva* for 30 to 60 s before it is reswallowed.

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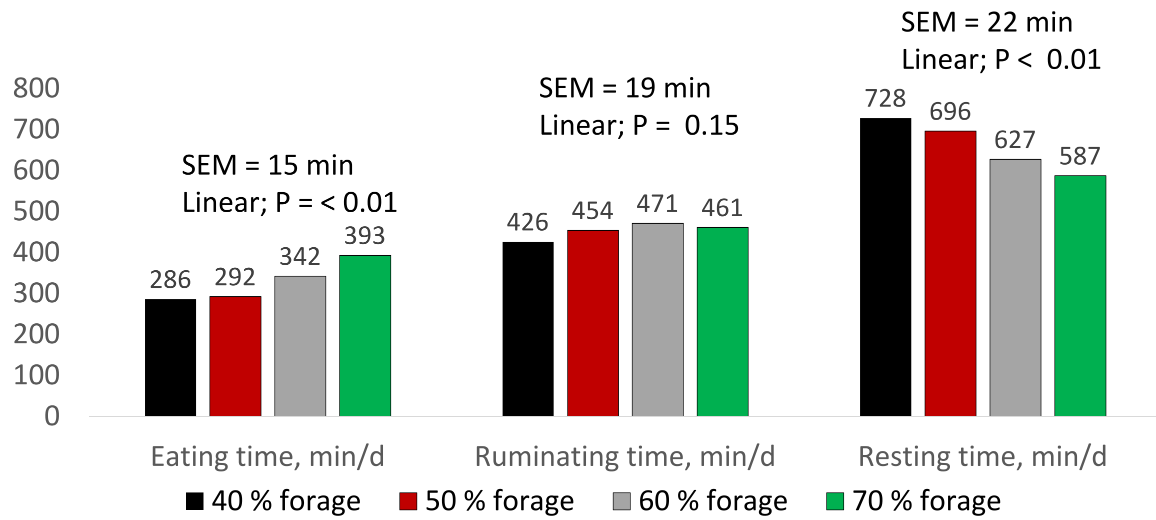
Proportion of forage and eating, ruminating and resting time, min/d



(Jiang et al., 2017)

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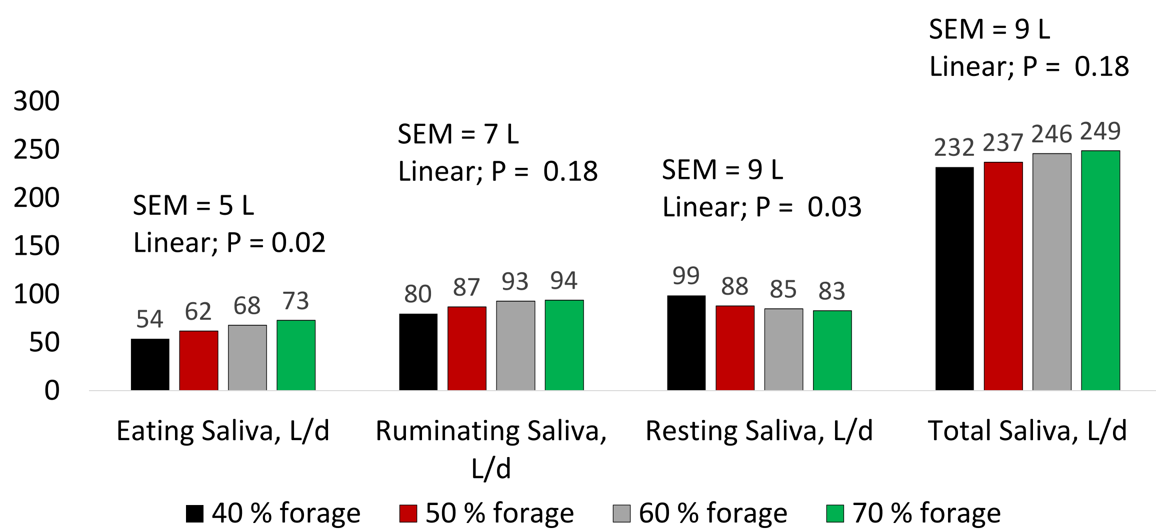
Proportion of forage and saliva production, mL/d



(Jiang et al., 2017)

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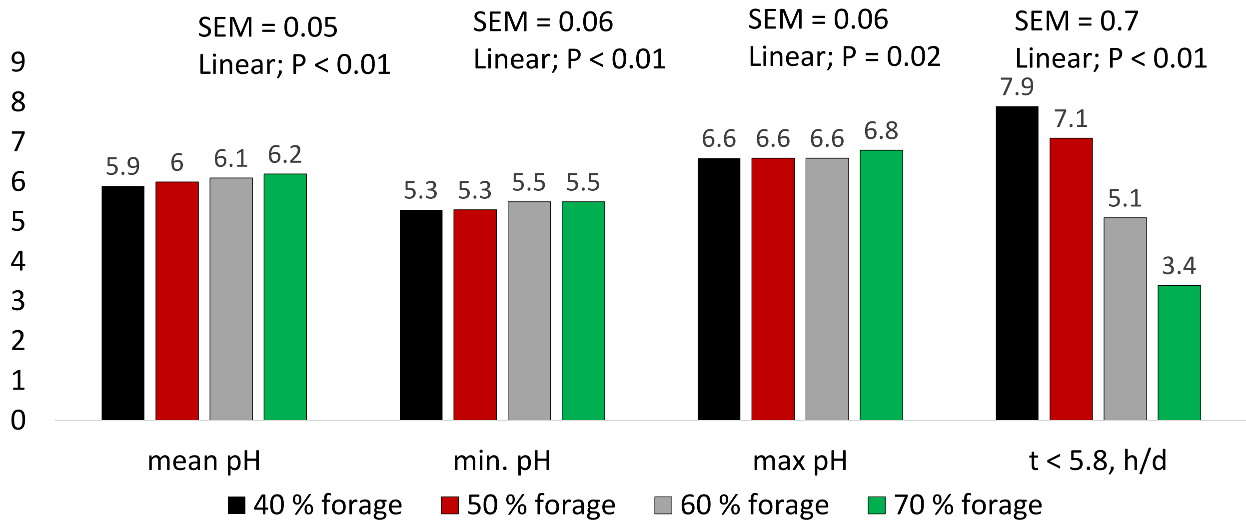
Proportion of forage and rumen pH



(Jiang et al., 2017)

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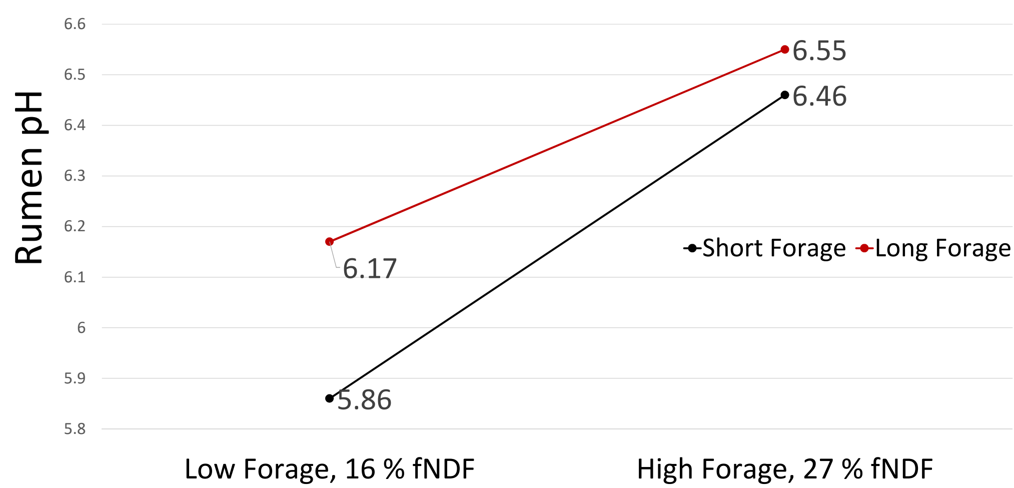
Moving beyond forage?



PS and fNDF *P* < 0.01, no interaction;
SEM = 0.13

Yang and Beauchemin et al., 2009

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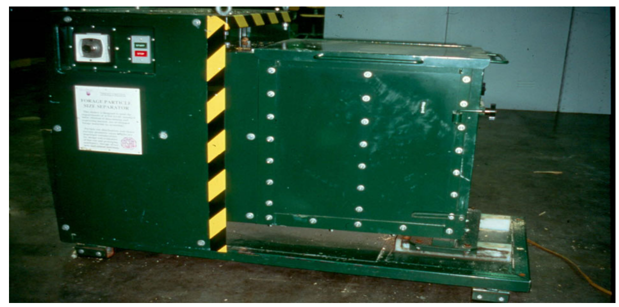
Methods to measure particle size

ASABE, S319.4,
vertical action

ASABE, S242.1,
horizontal action



Photos courtesy of AJ Heinrichs

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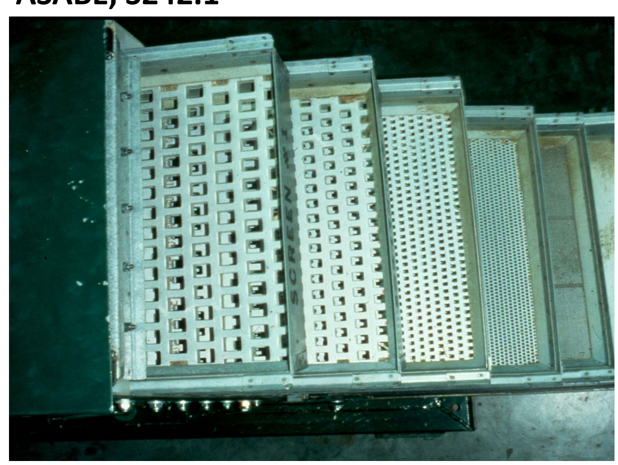
Methods to measure particle size

ASABE, S319.4

ASABE, S242.1



Photos courtesy of AJ Heinrichs

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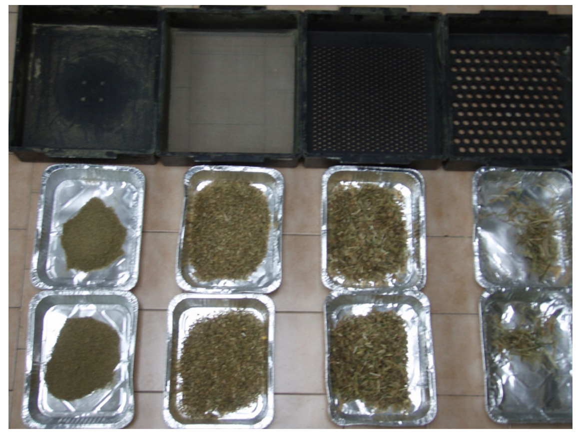
Penn State Particle Separator

Photos courtesy of AJ Heinrichs



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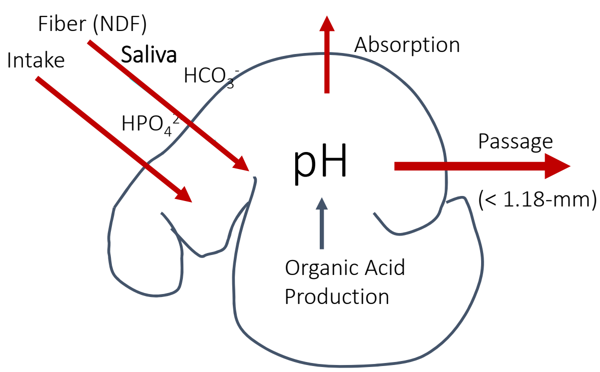
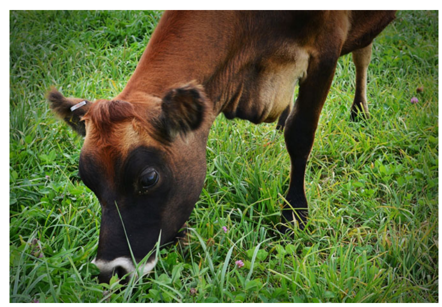
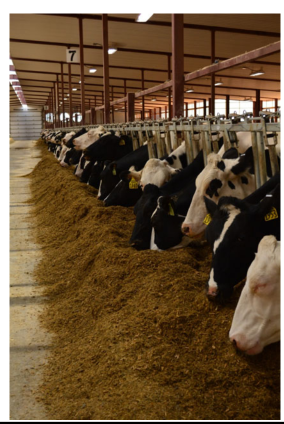
Effective Fiber







Factors affecting rumen pH

1 L of saliva = 7.5 g bicarbonate

(Erdman, 1988)

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Bicarbonate may be manipulated by:

1. Feeding

- 1% of diet DM would increase rumen inflow of bicarbonate by ~ 3-4%

2. Increasing Forage:Conc

- Increase rumen inflow of bicarbonate by ~ 5-6%

Jiang et al., 2018	40 % Forage	60 % forage
DMI, kg	22	20
Saliva production, L/d	232	246
Bicarb flow, g/d		
Saliva, g/d	1740	1845

3. Increasing particle size

- Saliva during chewing is believed to be ~ 0.206 L/min and resting is ~ 0.133 L/min
- ~Increase rumen inflow of bicarbonate by ~ 5-6%

Ramirez et al., 2016	Short Forage	Long Forage
DMI, kg	28	26
Chewing, min/d	556	737
Resting, min/d	884	703
Saliva production, L/d	232	245
Bicarb flow, g/d		
Saliva, g/d	1741	1840

(Adapted from Beauchemin et al., 2018)

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Measuring Effective Fiber

- As the particle size and fiber decrease roughage value decreases (Santini et al., 1983).
- Physically Effective NDF (peNDF)
  - Quantification of the roughage value.
  - That fraction of feed that stimulates chewing activity
  - peNDF of 22 required to maintain rumen pH > 6.0

(Mertens, 1997).

peNDF = % $\geq$ 1.18 mm X NDF

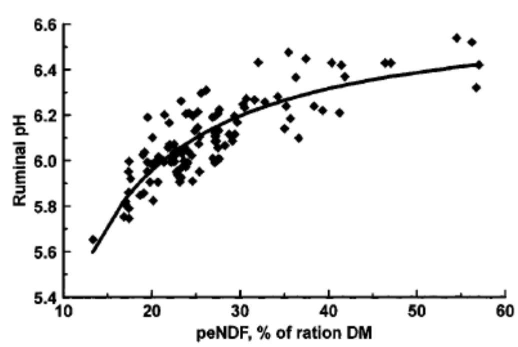

Figure 3. Relationship of observed ruminal pH adjusted for citation effects (♦) to physically effective neutral detergent fiber (peNDF) showing the reciprocal regression line [ruminal pH = 6.67 – 0.143(1/peNDF); r^2 = 0.71; SE = 0.10].

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Physically Effective NDF (peNDF)

- peNDF, 1.18 vertical sieving system
- Fermentability of CHO's no accounted for.

Assumptions when peNDF is used in nutrition models:

- that NDF is uniformly distributed over all particle sizes,
- that chewing activity is equal for all large particles
- that fragility (ease of particle size reduction) is not different among sources of NDF."

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Evaluation of Effective Fiber and Lactating Dairy Cow

Study I (White et al., 2017a): Deriving Equations that Identify Factors that Influence Effectiveness of Fiber

- The objective: to re-evaluate the concept of peNDF by quantitatively relating physical and chemical characteristics of total diets to DMI, chewing behavior, and ruminal pH.
  - Data generated using the PSPS was used to enhance the potential for the system to be used in on-farm situations

J. Dairy Sci. 100:9551–9568
https://doi.org/10.3168/jds.2017-12765

Physically adjusted neutral detergent fiber system for lactating dairy cow rations. I: Deriving equations that identify factors that influence effectiveness of fiber

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Study II (White et al., 2017b): Development of Feeding Recommendations

- The objective : to leverage equations derived in a meta-analysis into a multi-dimensional system for predicting dietary physical and chemical characteristics required to maintain desired rumen conditions.
  - Given the responsiveness of ruminal pH to animal behaviors and the chemical composition and physical form of the diet, mean ruminal pH was chosen

J. Dairy Sci. 100:9569–9584
https://doi.org/10.3168/jds.2017-12766

Physically adjusted neutral detergent fiber system for lactating dairy cow rations. II: Development of feeding recommendations

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Evaluation of factors that influence chewing and pH …

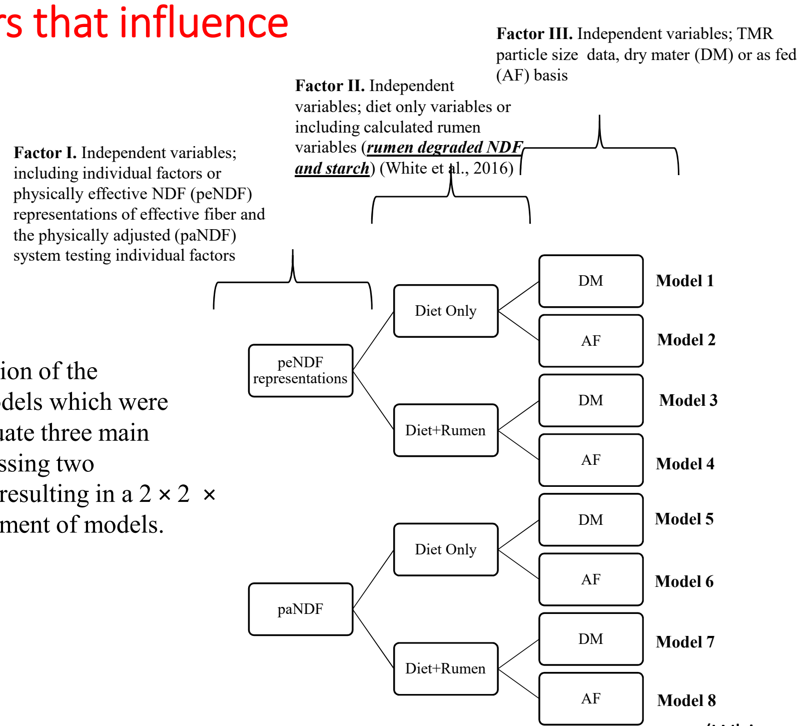

Figure 1-1. Depiction of the permutation of models which were developed to evaluate three main factors each possessing two combinations and resulting in a 2 × 2 × 2 factorial arrangement of models.

(White et al., 2017a)

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Table 9. Parameter estimates in models of **ruminal pH** when TMR particle size measure was (peNDF) or was not (paNDF) multiplied by diet NDF and including diet variables without (Diet) or with (Diet+Rumen) rumen digestibility when TMR sieved material was reported on an as fed (AF) or dry matter (DM) basis.[1]

	peNDF Representations				Individual Factors (paNDF) Representations			
	Diet		Diet+Rumen		Diet		Diet+Rumen	
Item[2]	DM[2]	AF[2]	DM[2]	AF[2]	DM[2]	AF[2]	DM[2]	AF[2]
Model no.	1	2	3	4	5	6	7	8
Intercept	13.8	12.0	4.21	6.72	4.15	12.0	4.53	12.0
MPS[3]	-0.124		-0.0739		-0.0712		-0.0708	
MPS[3] × NDF	0.279							
> 8 mm					0.0108		0.00955	
> 8 mm × NDF			0.0275					
Wet Forage	0.00727							
Legume Forage	0.0107							
fNDF		0.0112	0.0589	0.0137	0.0594	0.0112	0.0204	0.0112
fNDF × fNDF			-0.000852		-0.000875			
Starch	-0.0352	-0.0190	-0.00794	0.00798	-0.00849	-0.0190	-0.00708	-0.0190
Starch × Starch	0.000345	0.0003448				0.000348		0.000348
NDF					0.0198			
CP	-0.723	-0.679		-0.0456		-0.679		-0.679
CP × CP	0.0183	0.0186				0.0186		0.0186
Fat	-0.0690							
ADF/NDF			1.055		0.786		0.967	
dNDF[4]			0.00903				0.0114	
dStarch[5]				-0.00835				
Starch × MPS	0.00117		0.0016		0.0533		0.00150	
RumTime/DMI[6]		0.0152		0.0204		0.0152		0.0152
Fit Statistics								
N	33	123	71	123	77	123	71	123
CCC[7]	0.99	0.95	0.98	0.95	0.98	0.95	0.98	0.95
uCCC[8]	0.66	0.59	0.80	0.56	0.79	0.59	0.80	0.59
Var Study[9]	0.18	0.29	0.19	0.31 $\hat{\sigma}_e$	0.20	0.29	0.20	0.29
Var Error[10]	0.04	0.09	0.07	0.09	0.09	0.09	0.07	0.09

Chewing, ruminating and total were included but **only ruminating time per unit of DMI was an effector**

(White et al., 2017a)

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Some key observations from analysis

- Rumination
  - An index of effective fiber wasn't any better than handling all factors individually
  - dNDF and dStarch were associated w/rumination
- Rumen pH
  - Only rumination (and not chewing time) was an effector

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Modeling effective fiber, physically adjusted NDF (paNDF)

- Where are we at with a single model?

  - No dataset has *complete or balanced* coverage of all key independent variables

What is a Ensemble Model Approach (EMA)?

- technique that take a core concept (i.e. cow) and converting it into a "*constellation*" of models
- integrates equations with weighting factors over a range of conditions will be better at "future prediction"

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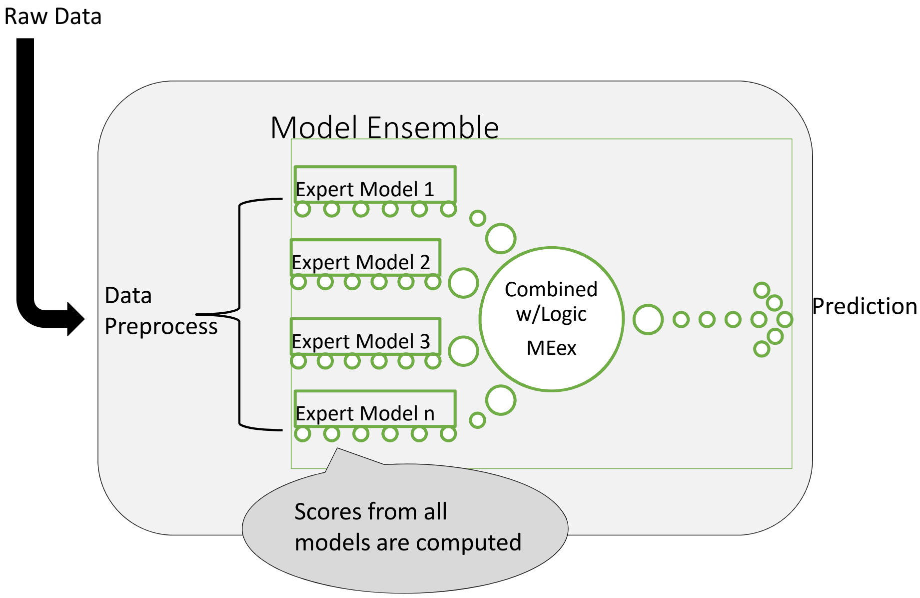
Development of Mixture of Experts (MEex): A model ensemble, scores from all models are computed and the final recommendation is determined by an average



http://www.ibm.com/developerworks/library/ba-predictive-analytics2/

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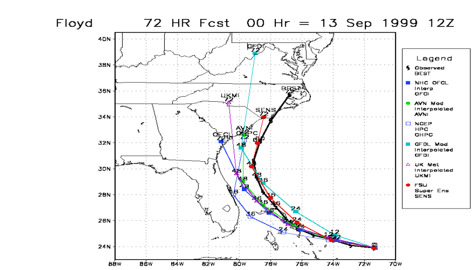
Popular use of Ensemble Models

- How many jelly beans in a jar?



- Weather prediction
  - Hurricane Floyd, 1998
- Netflix, 2006
  - $1 Million prize for a 10 % improvement over movie rating prediction (MSE = 0.9514)

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5 Models developed by White et al. (2017) and selected during ensemble model training for use in generating feeding recommendations. All units on DM basis.

Response	ID	Equation[1]
DMI, kg/d	1	-0.889 - 0.460 × MPS + 0.0203 × BW + 0.110 × Forage + 0.794 × NDF - 0.0117 × (NDF × NDF)
	5	-1.74 – 0.432 × MPS + 0.0218 × BW + 0.163 × Cottonseed + 0.117 × Forage – 0.238 × fNDF + 0.771 × NDF – 0.0116 × (NDF × NDF)
Rumination Time, min/d	3	-357 – 16.7 × MPS + 4.34 × 19mm + 2.49 × 8mm +71.5 × DMI – 1.54 × (DMI × DMI) + 4.78 × NDF – 1.68 × dNDF – 2.35 × dStarch
pH	2	12.0 + 0.0112 × fNDF – 0.0190 × Starch + 0.0003448 × (Starch × Starch) – 0.679 × CP + 0.0186 × (CP × CP) + 0.01052 × (Rumination Time/DMI)
	4	6.72+0.0137 × fNDF + 0.00798 × Starch – 0.0456 × CP – 0.00835 × dStarch + 0.0204 × (Rumination Time/DMI)

[1] MPS, Mean particle size in mm; BW, body weight in kg; Forage, % of forage in the TMR; NDF, % NDF in the TMR; Cottonseed, % of cottonseed in the TMR; fNDF, percent of forage NDF in the TMR; 19mm, % of TMR retained on the 19-mm sieve of the PSPS; 8mm, % of TMR retained on the 8-mm sieve of the PSPS; DMI, dry mater intake, kg/d; dNDF, rumen degraded NDF as estimated by White et al., 2017; dStarch, rumen degraded starch as estimated by (White et al., 2016); Starch, % of starch in the TMR; CP, % of CP in the TMR; Rumination time, time spend ruminating, min/d;

(White et al., 2017b)

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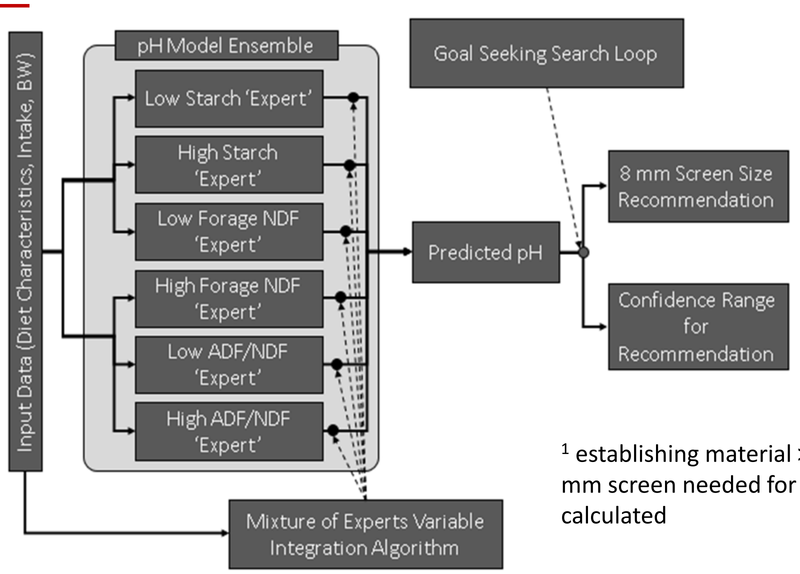
Mixture of Experts (Mex) trained to **predict % on 8 mm screen**



[1] establishing material > on 8 mm screen needed for pH is calculated

(White et al., 2017a)

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paNDF System

Key Findings

- peNDF was not ever the best predictor, an interaction term which can be *unbundled* by paNDF.
- Objective was *not to predict pH* per se but rather to see how PS and diet chemical composition "play together" to affect rumen conditions.
- fNDF was big influencer but PS improved prediction.
- Equations developed that predict "cascade" of factors.
  - DMI ➔Rumination➔ "Target pH"

Remaining Challenges

- Recommendations are on a DM basis
- Recommendations will have to be interpolated from large tables or computed electronically

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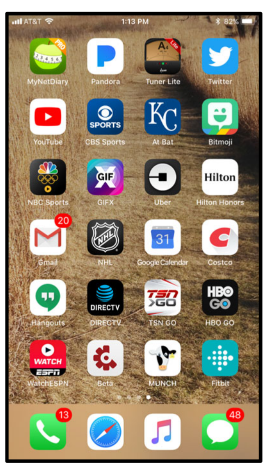
MUNCH … effective fiber evaluator, available soon!

Soon available at Google Play and App Store



Inputs

- Diet
  - NDF, ADF, CP, Starch, % > 19.0 mm (top screen of PSPS)
- Animal
  - Bodyweight, DMI, rumen pH "target" **NOT prediction!**
- Forage and Feed
  - fNDF, % forage (wet and dry), cottonseed
- Prediction
  - % on 8 mm sieve (second screen of PSPS), rumination time (minutes)

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Effect of changes in MUNCH input variables on recommended % of DM on 0.315-inch sieve of a Penn State Particle Separator and predicted minutes ruminating

Input	Change	0.315-inch sieve recommendation	Minutes ruminating
0.75-inch (“top”) sieve	8% to 12%	43.4±10 to 39.7±9%	**379 to 358**
NDF	NDF: 34 to 35% Starch: 25 to 24%	43.4±10 to 39.4±10%	**379 to 374**
Starch	NDF: 34 to 33% Starch: 25 to 26%	43.4±10 to 47.3±9%	**379 to 384**
Forage NDF	**24 to 26%**	**43.4±10 to 33.2±8%**	**379 to 358**

Morris et al., 2019

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Nutritional Dynamic System - NDS Professional

NDS PROFESSIONAL Ver. 3.9.7.10

Working group: First Working group | Set costs ($/Tons): SET 1 | Units system: Metric, English | Energy Units: Mcal, MJoule | Feedbank: BASE FEEDBANK

Distribution of particles		
Upper	12.50	87.54
Middle	37.80	49.74
Lower	10.10	39.56
Bottom Pan	39.60	

Guidelines for TMR	PSPS 2013
Upper	2 to 8 %
Middle	30 to 50 %
Lower	10 to 20 %
Bottom Pan	30 to 40 %

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Nutritional Dynamic System - NDS Professional

NDS PROFESSIONAL Ver. 3.9.7.10

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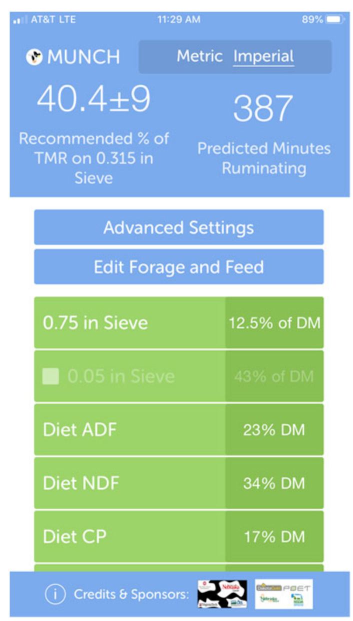

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