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Systems and indices for the evaluation of physical feed structure in ruminant nutrition

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Structural value	van de Boever et al., 1993; de Brabander, 1999
Physically effective NDF	Mertens, 1997, 2000; Kononoff, 2002; Zebeli et al., 2008, 2012

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Definition „Feed structure"

"**Feed structure**" is the sum of properties of a feed characterised by its **physical form** and **content of structural substances** describing its **"fibrousness"**(Hoffmann, 1983, 1990).

"**Fibre**" describes **heterogeneous polymeric substances** that cannot be cleaved by digestive enzymes of vertebrates but is an essential nutrient for **maintaining physiological conditions in rumen** (Gruber, 2009).

Physical form:
- Particle size
- Size distribution
- Rigidity
- Specific gravity
- …

vs.

Structural substances:
- Hemicellulose
- Cellulose
- Lignin
- (Pectin)
- …

Effects on:
- Chewing activity
- DMI, feeding frequency
- Concentrate proportion (NFCs)
- Fermentability of nutrients
- Ruminal passage rate
- Buffering capacity of ration
- Ruminal pH and VFA
- Milk fat content
- …

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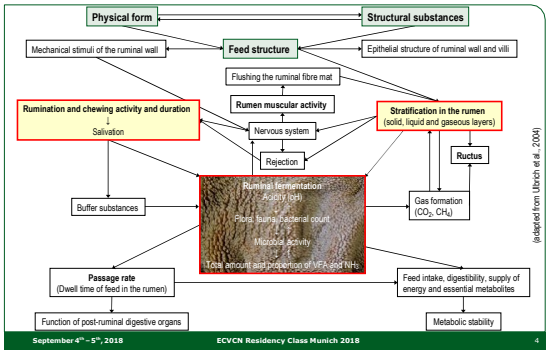
Feed structure in ruminant nutrition



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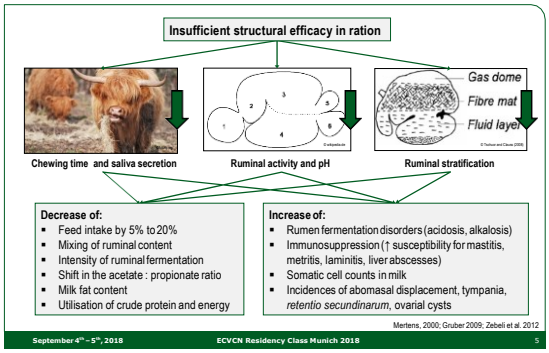
Effects of insufficient structural efficacy in rations for dairy cows



Mertens, 2000; Gruber 2009; Zebeli et al. 2012

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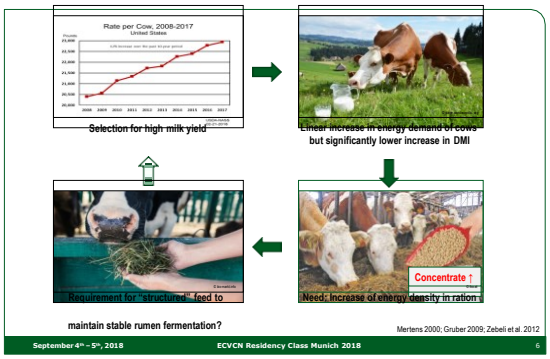
Feed structure in ruminant nutrition



Mertens 2000; Gruber 2009; Zebeli et al. 2012

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Feed structure in ruminant nutrition

Precise knowledge of physiological ruminal processes is essential to determine ruminants' requirement for "structured" feed!

To examine and assess the supply of "structured" feed in ruminants for ration calculation and control nutritionists need comprehensive and reliable systems and indices to reflect the situation in rumen properly.

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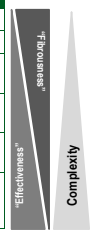

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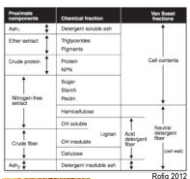
Crude fibre (CF)
(Henneberg and Stohmann, 1864)

- Includes insoluble parts of cellulose, pentosane, lignin, suberin, and cutin
- Covers only 32% to 79% of structural substances (NDF) depending on feed type, vegetation phase, treatment and analytical method
- Insufficient and sometimes chemically inaccurate description of carbohydrates as crude fibre and N-free extracts (soluble parts of NDF!)
- Only chemical parameter → no consideration of physical properties (e.g. unground vs. ground hay or straw)



Rotiq 2012

Recommendation for dairy cow rations:
→ **18% CF in DM** with two-thirds deriving from forage

vs.

van Soest, 1977; NRC, 2001; Jeroch et al., 2008; Gruber, 2009

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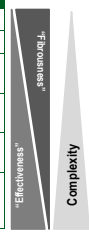

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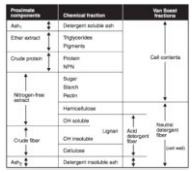
Neutral detergent fibre (NDF)
(van Soest, 1967)

- Progress compared to CF → sum of structural substances soluble at pH 7(without pectin)
- Highly correlated with rumination time and chewing activity
- Used in Cornell Net Carbohydrate and Protein System(CNCPS)

- Disadvantages:
  - Pectins are completely solved (neutral detergent soluble fibre, NDSF)
  - Only chemical parameter → no consideration of physical properties
  - Insufficient and sometimes chemically inaccurate description of carbohydrates as NDF, ADF and NFC



Rotiq 2012

Recommendation for dairy cow rations (NRC, 2001):
→ ≥ 25% NDF of DM (19% NDF from forages)
≤ 44% NFC of DM

van Soest, 1977; NRC, 2001; Jeroch et al., 2008; Gruber, 2009

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Neutral detergent fibre (NDF)
(van Soest, 1967)

NDF from forage (% of DM)	Minimum total NDF in diet (% of DM)	Maximum total NFC (% of DM)	Minimum total ADF in diet (% of DM)
19	25	44	17
18	27	42	18
17	29	40	19
16	31	38	20
15	33	36	21

NFC = 100 – NDF - CP - CL - CA

NRC, 2001

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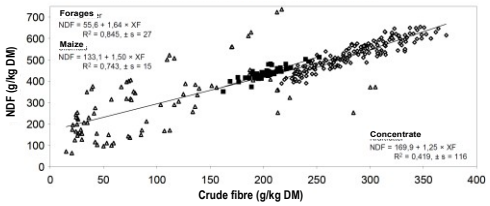
Crude fibre (CF) and neutral detergent fibre (NDF)

Relationship between crude fibre (CF) and NDF



- Close positive relationship between CF and NDF/ADF (→ type of feed)
- Negative correlation between CF/NDF and energy concentration

Mahlkow-Nerge, 1999; Gruber, 2009

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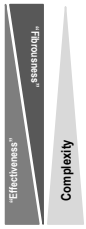

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Roughage value index (RVI) and chewing acitivity

- Characterising biological response to feed's physical properties (fibrousness)
- Sudweeks et al. (1979, 1981):
  - Roughage value index (RVI)
    - Feed specific total chewing time in min per kg DM
    - Minimum to maintain milk fat percentage: 30 min per kg DM
- Nørgaard (1986):
  - Physical structure system (chewing index) based on type of feed and particle size

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Characteristic	Degree of grinding		Degree of chopping (F[a])		
	Finely ground	Coarsely ground	Fine F = 0.25	Coarse F = 0.75	None or slight F = 1.0
Physical structure group	1	1	2	2	2
Typical feedstuffs	Concentrate, molasses	Rolled barley, dried grass cubes	Beet pulp	Finely chopped grass silage	Long hay, long straw, beets, fresh grass
Average particle size, mm	< 1	1 - 5	5 - 10	10 - 50	> 50
Standard chewing time (min/kg DM)	4	10	calculated[b]	calculated[b]	calculated[b]

a: weighting factor for the effect of chopping
b: standard chewing time = F x 3 x % crude fibre (CF) which assumes 300 min of chewing per kg CF for unchopped feeds

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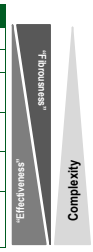

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Structural effective crude fibre (seCF)
(Hoffmann et al., 1990; Piatkowski et al., 1990)

- Based on measurements of chewing behaviour and activity, salivation, rumination, fermentation etc.
- "Structural effective" = dry, in water largely resistant particles (cattle: > 8 mm)
- Calculable for each feedstuff and proportionately addable to total ration
- Derivation of structural effectiveness based on chewing time measurements (1 kg seCF in 3 hours)
  - Depending on feed type, vegetation stage, grinding grade → different multiplicators (se factor)
- Disadvantages:
  - No mandatory values for different feeds (Steingaß and Zebeli, 2001)
  - No consideration of highly soluble carbohydrates (e.g. concentrates!)
  - No consideration of milk yield or feed intake (but body weight)

Hay (26 to 30% CF)	**1.0**
Straw	
- Long, chopped	1.5
- Short, chopped	1.0
- Ground	0.5
Gras silage	
- Wet	0.75
- Wilted	1.0
Corn silage	1.0
Sugar beet leaf silage	0.5
Dry beet pulp	0
Barley, oat	0

seCF = CF x se factor

Hoffmann et al., 1990; Piatkowski et al., 1990

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Structural effective crude fibre (seCF)
(Hoffmann et al., 1990; Piatkowski et al., 1990)

Daily recommendation for dairy cow rations

Per 100 kg BW and day	Minimum > 300 g	Optimum 400 g (350 - 450)	Maximum < 500 g
BW, kg		**kg per cow and day**	
550	1.7	2.2	2.8
600	1.8	2.4	3.0
650	2.0	2.6	3.2
700	2.1	2.8	3.5
750	2.3	3.0	3.8

Hoffmann et al., 1990; Piatkowski et al., 1990

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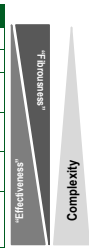

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Structural value (SV)
(de Boever et al., 1993a, 1993b; de Brabander et al., 1999, 2002)

- Determination of a "critical forage proportion"
  - Signs of structural deficiency (↓ milk fat, feed intake) when concentrates are added to forages
- SV of forages and corn silages calculated via CF and/or NDF
- SV of corn silages requires a correction depending on its chopping length
- SV of concentrates considers concentrations of starch, sugar and undegradable starch
- Calculable for each feedstuff and proportionately addable to total ration (dimensionless number)
- Recommendations are given for varying milk yields and milk fat concentrations (SV = 0.94 to 1.18)

Recommendation of minimum supply for dairy cow rations:
→ **SV = 1 per kg DM**
(valid for 1st to 3rd lactation, 25 kg milk yield, concentrate 2x/d)

de Boever et al. 1993a, 1993b; de Brabander et al., 1999; de Brabander et al., 2002

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Structural value (SV)
(de Boever et al., 1993a, 1993b; de Brabander et al., 1999, 2002)

Calculation of SV

Feedstuff	Calculation
Gras silage (CL > 20 mm)	SV = 0.0125 x **CF** - 0.2
	SV = 0.006 x **NDF** + 0.15
Corn silage	SV = (0.009 x **CF** - 0.1) x (1 + ((**CL** - 6) x 0.02))
	SV = (0.006 x **NDF** - 0.57) x (1 + ((**CL** - 6) x 0.02))
Hay	SV = (0.0125 x **CF** - 0.2) x 1.06
	SV = 0.006 x **NDF** + 0.15
Straw	SV = 4.3
Concentrate	SV = 0.321 + 0.00098 x **CF** + 0.00025 x b x **starch** - 0.00112 x (**sugar** + a x (**starch** - b x **starch**))
CAVE!	SV = 0.175 x 0.00082 x **NDF** + 0.00047 x b x **starch** - 0.001 x (**sugar** + a x (**starch** - b x **starch**))
	a = 0.9 - 1.3 x b

CF, NDF, starch, sugar in g/kg DM; CL = theoretical chopping length (mm); b = coefficient of durability

de Boever et al. 1993a, 1993b; de Brabander et al., 1999; de Brabander et al., 2002

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Structural value (SV)
(de Brabander et al., 1999; de Brabander et al., 2002)

Adjustments of SV

- +/- 0.01 per kg **milk** higher/lower than 25 kg
- +/- 0.005 per g **milk fat** lower/higher than 44 g/kg ?
- -0.1 for **distribution of concentrates** (6 per day or TMR)
- -0.07 for cows in the **4th lactation** ?
- -0.15 for cows in the **5th lactation**

Milk fat (%)	Milk yield (kg/day)			
	15	25	35	45
3.6	0.94	1.04	1.14	1.24
4.0	0.92	1.02	1.12	1.22
4.4	0.90	1.00	1.10	1.20
4.8	0.88	0.98	1.08	1.18

Experiences from practice: Signs of structural deficiency (refusal to feed), although SV was sufficiently calculated (Meyer et al., 2002)

de Brabander et al., 1999; de Brabander et al., 2002

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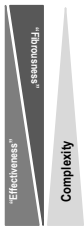

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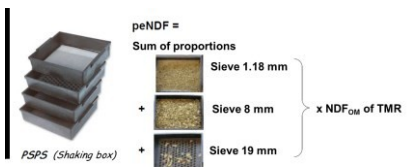
Physically effective NDF (peNDF)
(Steingaß and Zebeli, 2008; Zebeli et al., 2008, 2010)

- Extension of the peNDF system of Mertens (1997,2001)
- Combination of chemically analysed NDF content and physical properties of feed
  - Determination of sieve fraction > 1.18 mm ("critical particle size" *) and calculation with NDF content of ration ($peNDF_{>1.18\,mm}$) using Penn State Forage Particle Separator (PSPS)

* Derived from experiments investigating chewing activity, milk fat content and ruminal pH



peNDF =
Sum of proportions
Sieve 1.18 mm
+ Sieve 8 mm
+ Sieve 19 mm
x NDF_{OM} of TMR

- Reference parameter: ruminal pH (!) and stratification

(Steingaß and Zebeli, 2008; Zebeli et al., 2008, 2010)

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Physically effective NDF (peNDF)
(Steingaß and Zebeli, 2008; Zebeli et al., 2008, 2010)

- Consideration of average daily ruminal pH, particle size and concentration of rumen degradable starch from grain (RDSG)
- Consideration of particle size of rations on the farm including all possible effects before feed intake by the animal (e. g. chopping length, strong grinding in fodder mixer)
- Designed for TMR rations with high proportion of concentrate

- Disadvantage: Extent and rapidity of ruminal fermentation of feedstuffs are not taken into account (NRC, 2001)
  - Advantage compared to previous systems?
  - Only for control of entire rations and not for their calculation
  - Not additive for components of rations

Requirement of peNDF$_{>1.18mm}$ (% of DM):

6.05 + (0.044 **peNDF$_{>1.18mm}$**, % DM)
- (0.006 **peNDF$_{>1.18mm}^2$**, % DM)
- 0.017 **RDSG** (% DM)
- 0.016 **DMI** (kg/d)

(Steingaß and Zebeli, 20018 Zebeli et al., 2008, 2010)

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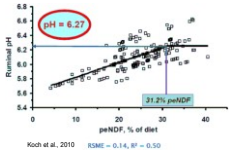
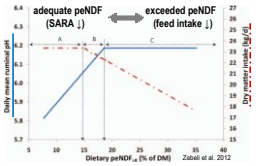
Physically effective NDF (peNDF)
(Steingaß and Zebeli, 2008; Zebeli et al., 2008, 2010)

- ruminal pH:
  - Most reliable value to characterise the structural supply
  - Prevention of SARA:
    - Daily average > pH 6.15
    - < 5.24 to 5.47 h per day below pH 5.8





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Physically effective NDF (peNDF)
(Steingaß and Zebeli, 2008; Zebeli et al., 2008, 2010)

Concentration of peNDF (% of DM) depending on daily feed intake and dietary RDSG concentration (ruminal pH ≥ 6.27)

RDSG (% of DM)	Feed intake (kg DM/cow)				
	18	20	22	24	26
10	28.5	29.2	29.9	30.7	31.4
14	30.0	30.8	31.5	32.2	32.9
18	31.6	32.3	33.0	33.8	34.5
22	33.1	33.8	34.6	35.3	36.0

(Steingaß and Zebeli, 2008; Zebeli et al., 2008, 2010)

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Conclusions and Outlook

Demands on evaluation systems:

- Consideration of the complex interaction between structural effectiveness of feeds/rations and physiological rumen processes (→ biological response!)
- Consideration of the two-factorial character of „structural effectiveness" of feeds:
  - Physical form: particle size distribution (standardised laboratory method)
  - Structural substances: CF and/or NDF (analytically defined)
  - (easily fermentable carbohydrates; NFC)
- Structural effectiveness must be assessable and addable for ration components (calculation, control)
- Recommendations for structural supply must be given as weight unit (e.g. kg/cow/d; % of DM)
- Future focus on special situations:

➡ The **abundance of different systems** indicates that structural evaluation of feedstuffs is of pivotal importance in ruminant nutrition!

➡ However, there is **no system** for assessing structural effectiveness of feedstuffs **comprehensively**. Therefore, current reference values can only be used for guidance! (GfE, 2001)

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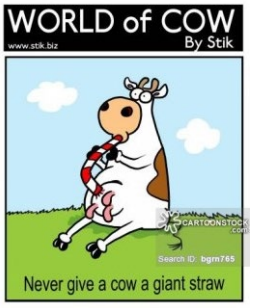
Thank you for your attention.



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Effects of decreased structural efficacy in rations for dairy cows

Variable	% Long grass hay in the diet					
	100	80	60	40	20	0
NDF, %	70	59	48	36	25	14
peNDF, %	70	57	44	32	18	6
Chewing time, min/d	1080	1040	970	820	520	320
Saliva secretion, L/d	200	196	189	174	143	123
Salivary bicarbonate, kg/d	2.5	2.4	2.3	2.2	1.8	1.5
Ruminal pH	6.8	6.7	6.5	6.2	5.8	5.0
Ruminal VFA, mM	85	95	105	115	125	135
Ruminal acetate, molar %	70	66	61	55	48	40
Ruminal propionate, molar %	15	18	22	27	33	40
A : P ratio	4.7	3.7	2.8	2.0	1.4	1.0
Milk fat, %	3.7	3.6	3.5	3.4	3.0	1.0

Mertens, 2000

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Physically effective NDF (peNDF)

(Mertens, 1997, 2000)

- Combination of chemically analysed NDF content and physical properties of feed (animal independent)
- Evaluated via regression models of daily NDF intake (kg/d) and total chewing time (min/d)
  - Zero intercept linear model (no feed intake → no chewing activity)
  - Regression coefficients describe chewing activity (min per kg NDF) from each source and form
    - Long grass hay resulted in 150 min of chewing per kg NDF → standard pef = 1.00

Physical effectiveness factors (pef) per kg of NDF from various sources and physical forms (Mertens, 2000)

Classification	Grass hay	Grass silage	Corn silage	Alfalfa hay	Alfalfa silage	Concentrates	By-products
Long	1.00			0.9			
Coarse chopped	0.95	0.95	0.90	0.9			
Medium chopped	0.90	0.90	0.85	0.8			
Fine chopped		0.85	0.80	0.7			
Rolled corn							
Rolled barley							
Rolled/coarse ground							
Medium ground	0.40			0.4			
Ground/pelleted							

peNDF = NDF (% of DM) x pef

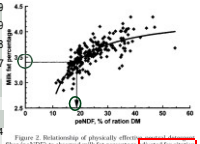

Figure 2. Relationship of physically effective [illegible] observed milk fat percentage [illegible] reciprocal regression line [milk fat = 4.32 − 0.17/(1/peNDF); r^2 = 0.62, SE = 0.17] and the [illegible] (Mertens, 1997).