Introdução à modelagem da nutrição e do crescimento de ruminantes

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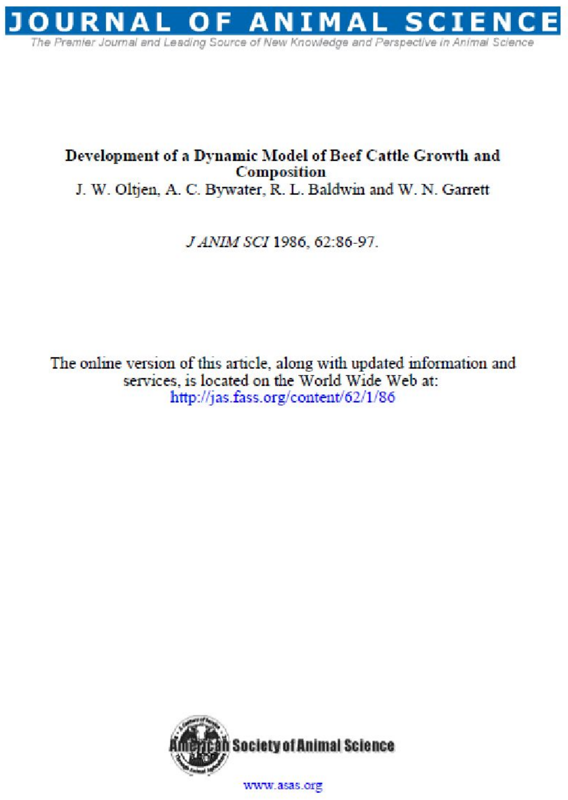
02 Ago 2019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Development of a Dynamic Model of Beef Cattle Growth and Composition

J. W. Oltjen, A. C. Bywater, R. L. Baldwin and W. N. Garrett

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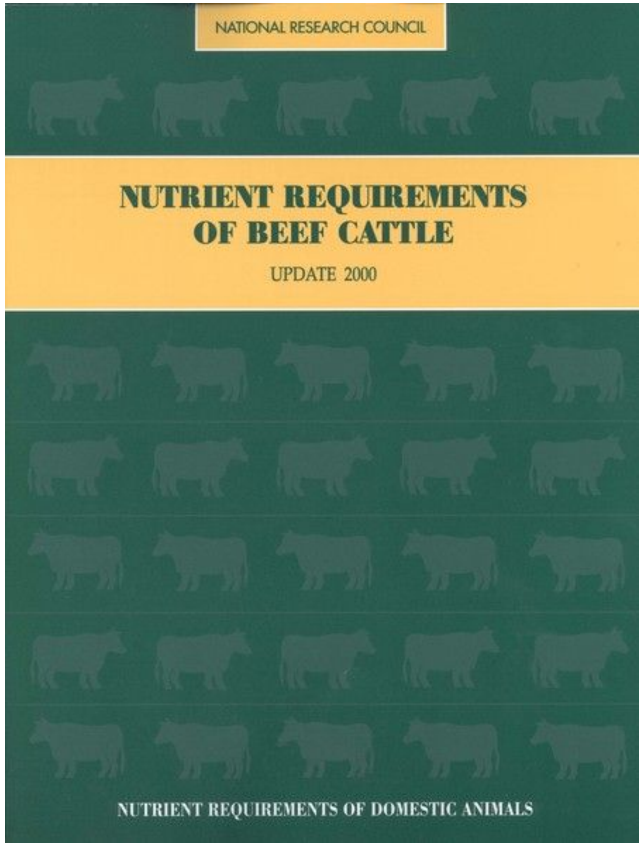
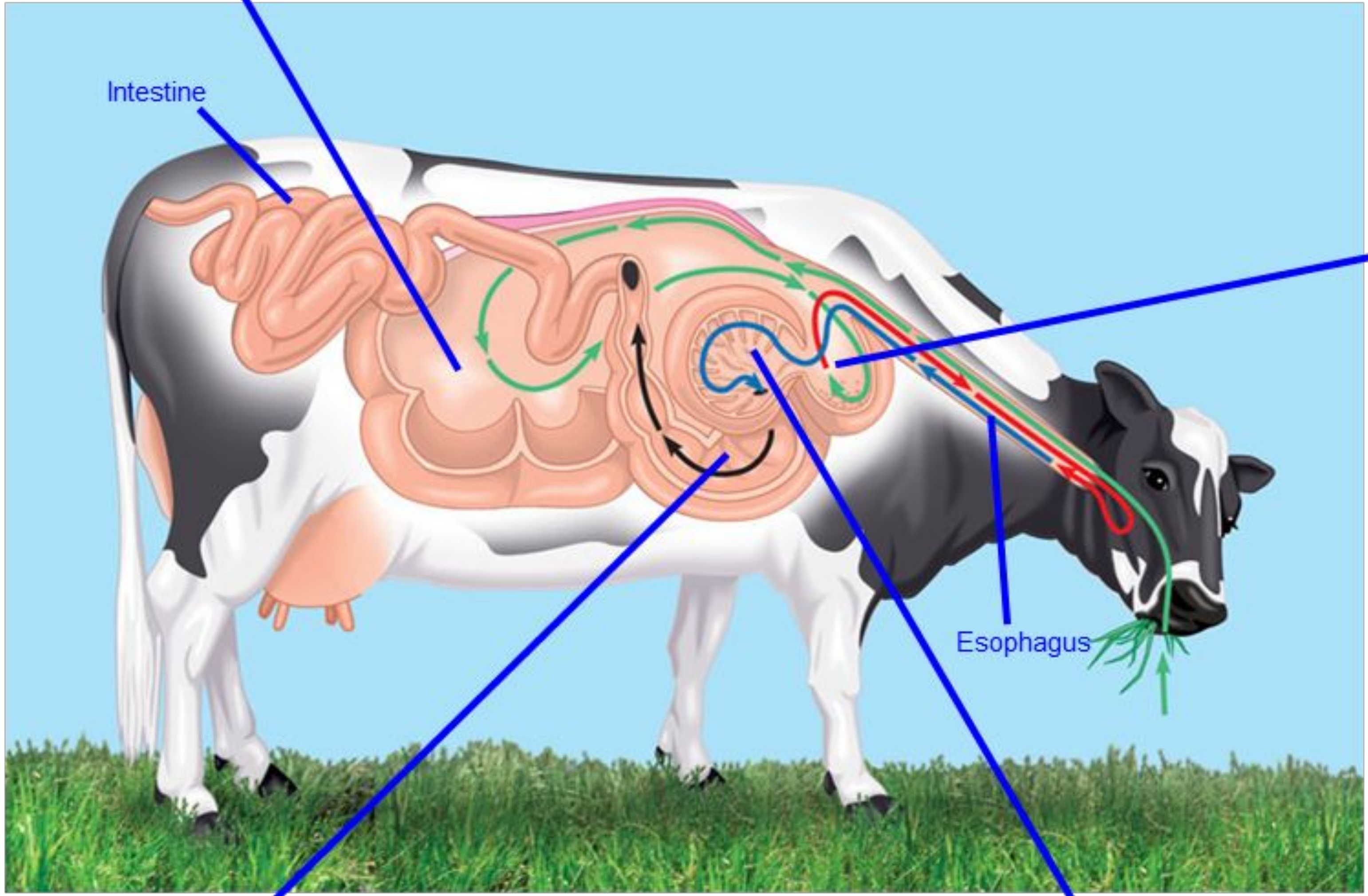


Bibliografia

1 Rumen. When the cow first chews and swallows a mouthful of grass, boluses (green arrows) enter the rumen.



2 Reticulum. Some boluses also enter the reticulum. In both the rumen and the reticulum, symbiotic prokaryotes and protists (mainly ciliates) go to work on the cellulose-rich meal. As by-products of their metabolism, the microorganisms secrete fatty acids. The cow periodically regurgitates and rechews the cud (red arrows), which further breaks down the fibers, making them more accessible to further microbial action.

3 Omasum. The cow then reswallows the cud (blue arrows), which moves to the omasum, where water is removed.

4 Abomasum. The cud, containing great numbers of microorganisms, finally passes to the abomasum for digestion by the cow's own enzymes (black arrows).

kp: passage rate

kd: degradation rate

Feed Energy Partition

Gross Energy (GE)

→ Fecal energy

Digestible Energy (DE)

→ Urinary energy
Gaseous energy

Metabolizable Energy (ME)

→ Heat Increment

Net Energy (NE)

→ Maintenance
Growth
Lactation
Wool production
Activity

$$GE \cong 18.5 \text{ MJ/kg DM} \cong 4.42 \text{ Mcal/kg DM}$$

$$DE = GE * dig$$

Digestibility (45-85%)

$$ME \cong 0.82 * \mathrm{DE}$$

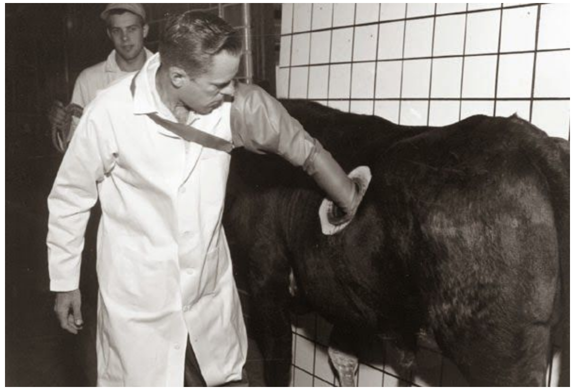
Code

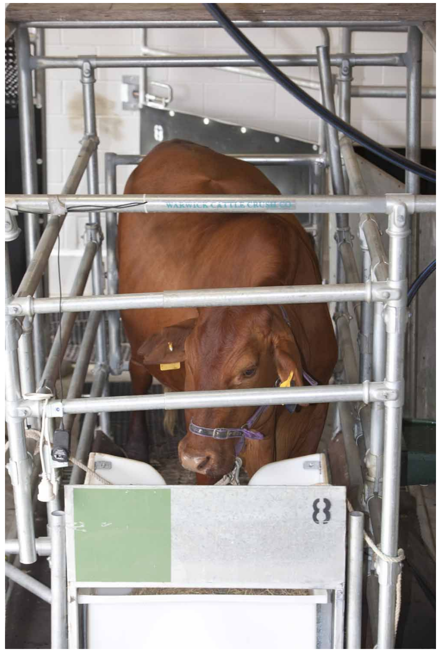
$$NE_m = 1.37 \cdot \mathrm{ME} - 0.138 \cdot \mathrm{ME}^2 + 0.0105 \cdot \mathrm{ME}^3 - 1.12$$

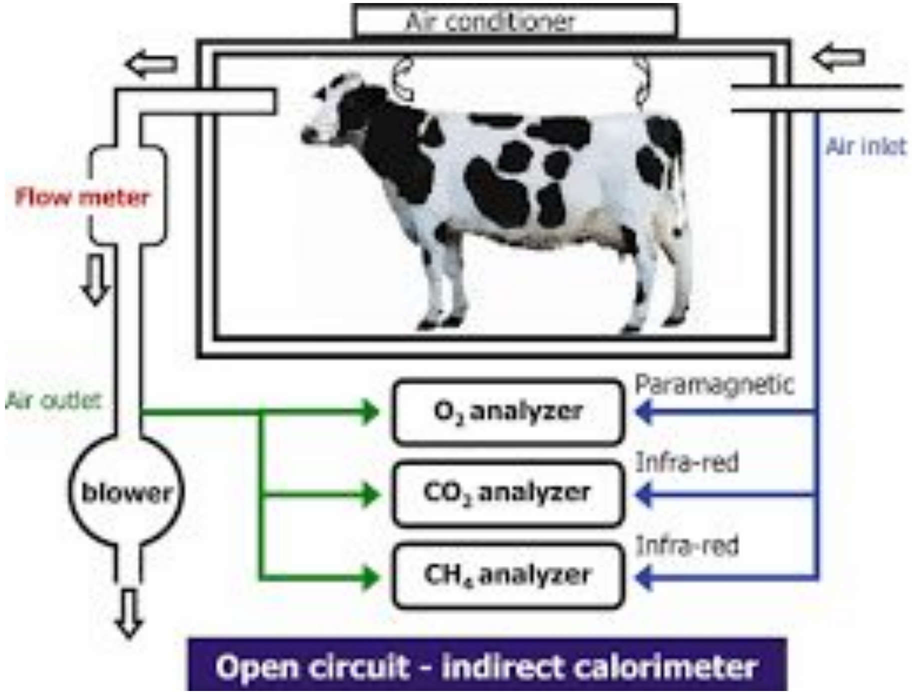
$$NE_g = 1.42 \cdot \mathrm{ME} - 0.174 \cdot \mathrm{ME}^2 + 0.0122 \cdot \mathrm{ME}^3 - 1.65$$

(Garrett, 1980; NRC, 2015)

Feed Energy Measurement

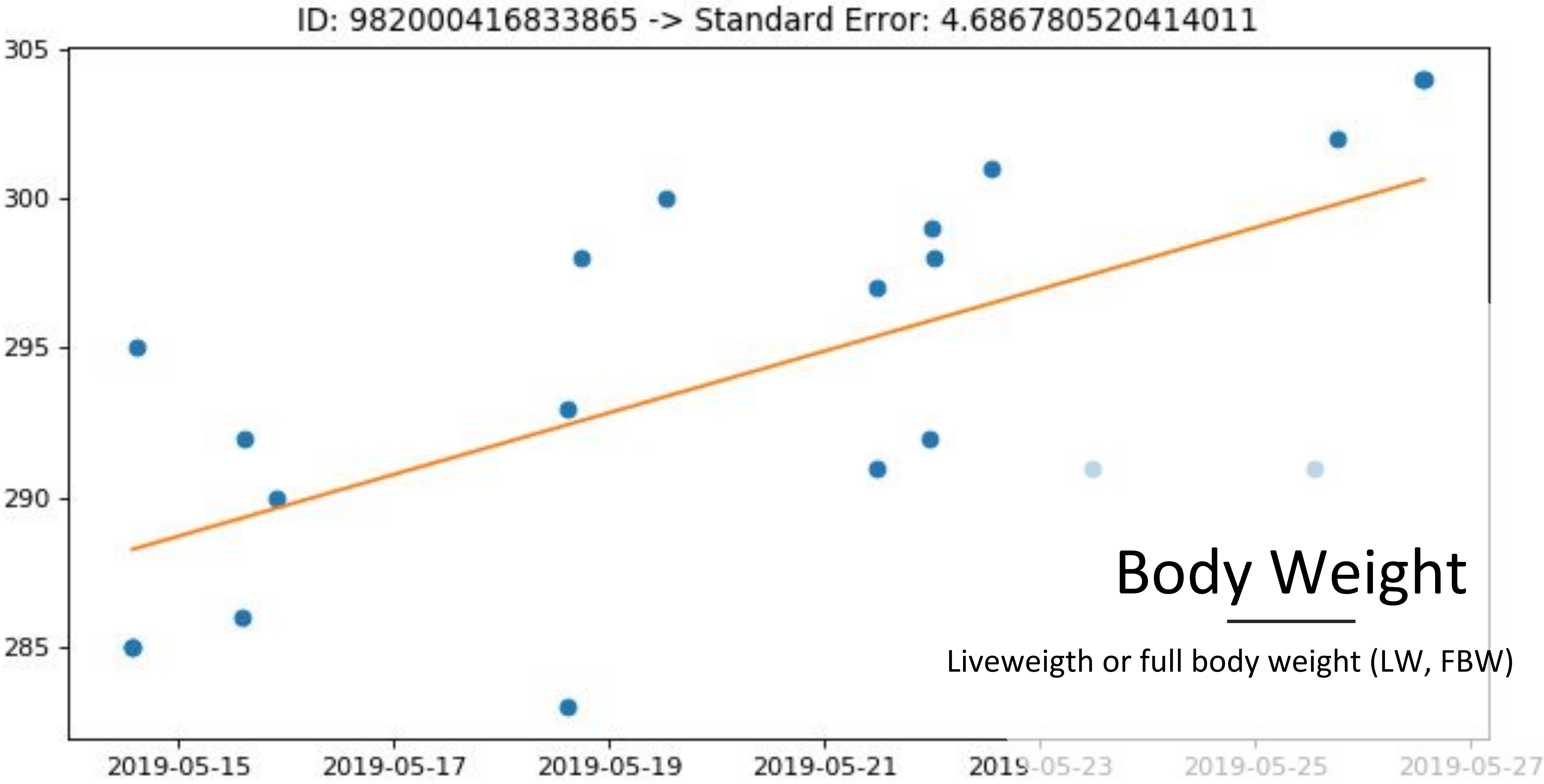






Tables of feed nutritional value

Entry No.	Feed Name/ Description	International Feed No.	Value as Determined at Maintenance Intake: TDN (%)	DE (Mcal/kg)	ME (Mcal/kg)	Net Energy Values for Growing-Cattle Mcal/kg: NE_m	NE_g	Dry Matter (%)	Crude Protein (%)	Ruminal Undegradability (%)	Ether Extract (%)	Fiber (%)	NDF (%)	ADF (%)
	ORCHARD GRASS (*Dactylis glomerata*)													
58	Fresh, early bloom	2-03-442	68	3.00	2.46	1.57	0.97	23.5	12.8	20	3.70	32.00	58.1	30.70
		N	—	—	—	—	—	8	7	—	5	5	3	2
		SD	—	—	—	—	—	3.87	2.37	—	0.80	2.93	8.31	1.98
59	Fresh, mid-bloom	2-03-443	57	2.51	2.06	1.21	0.64	27.4	10.1	22	3.5	33.5	57.6	35.6
		N	—	—	—	—	—	3	4	—	2	2	1	1
		SD	—	—	—	—	—	5.36	3.89	—	0.36	2.25	—	—
60	Hay, sun-cured, early bloom	1-03-425	65	2.87	2.35	1.47	0.88	89.1	12.8	24	2.9	33.9	59.6	33.8
		N	—	—	—	—	—	7	9	—	6	5	4	4
		SD	—	—	—	—	—	3.30	3.51	—	0.82	1.72	5.28	1.25
61	Hay, sun-cured, late bloom	1-03-428	54	2.38	1.95	1.11	0.55	90.6	8.4	24	3.4	37.1	65.0	37.8
		N	—	—	—	—	—	7	1	—	1	1	3	3
		SD	—	—	—	—	—	1.51	—	—	—	—	2.77	0.20



Body Weight

Liveweigth or full body weight (LW, FBW)

Body Weight

- Shrunk Body Weight (SBW) – 16 h fasting

SBW$= 0.96 * LW$

- Empty Body Weight (EBW)

$$EBW = 0.891 * SBW$$

$$EBW = 0.891 * 0.96 * LW$$

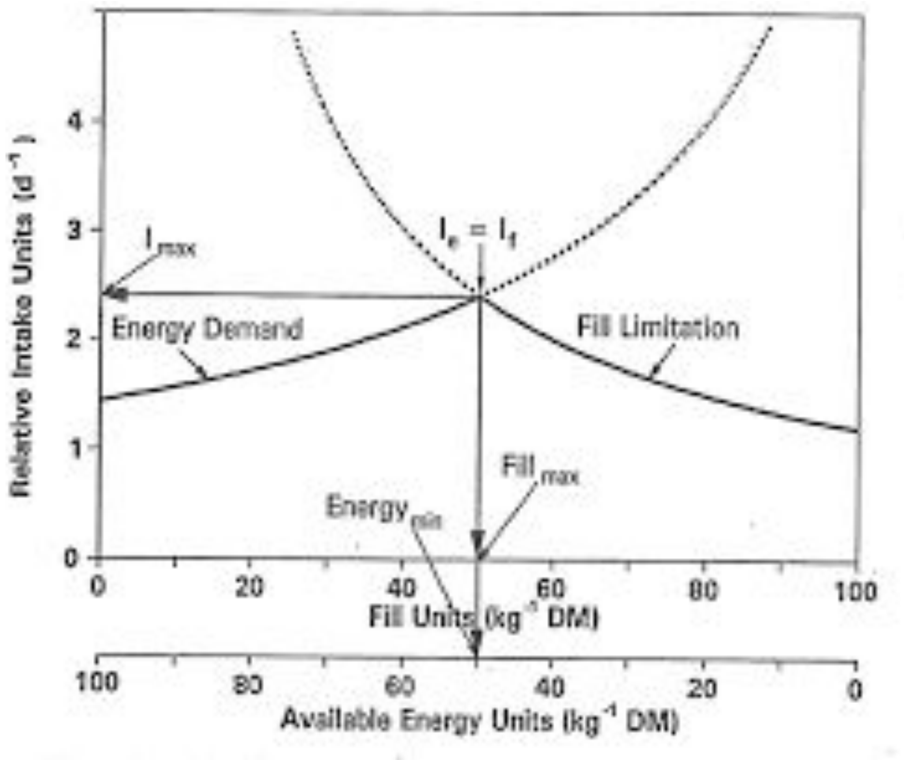
$$EBW = 0.85536 * LW$$

Alternatively, the equation of Williams et al. (1992; EBW=full BW * [1-gut fill], where gut fill is 0.0534+0.329 * fractional forage NDF) can be used to predict EBW from unshrunk liveweight.

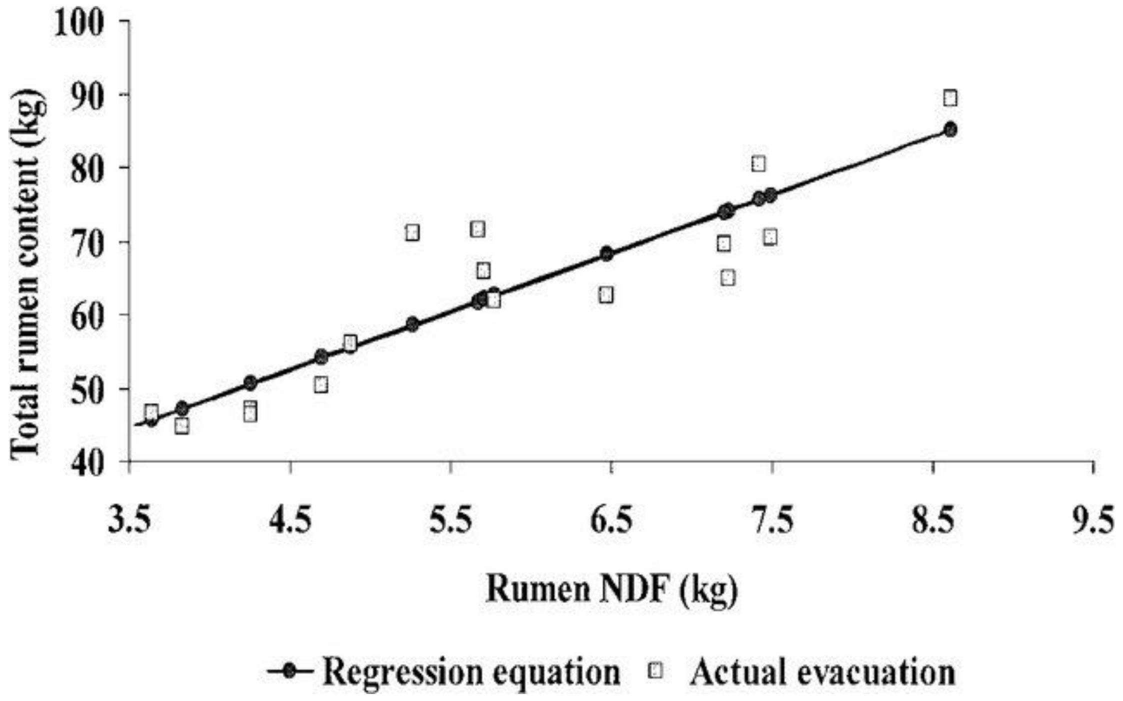
Code

Feed Intake

Rumen fill vs chemostatic (physiologic limit)



Source: Mertens (1987)



Source: Khorasani et al. (2001)

Feed Intake (NRC model)

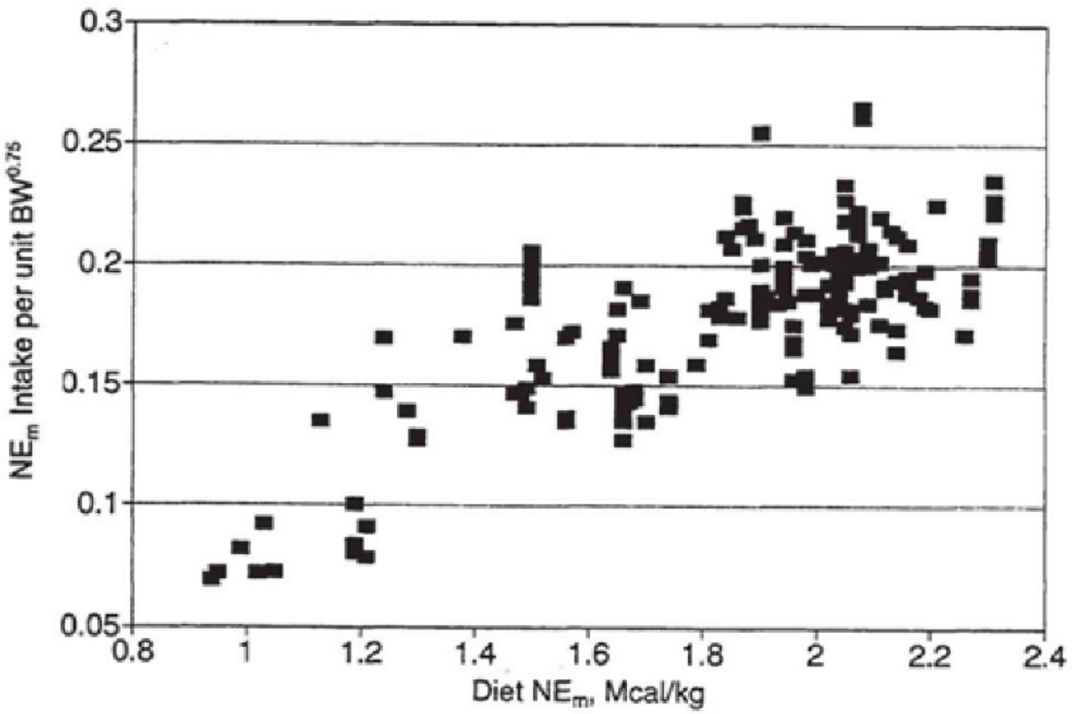


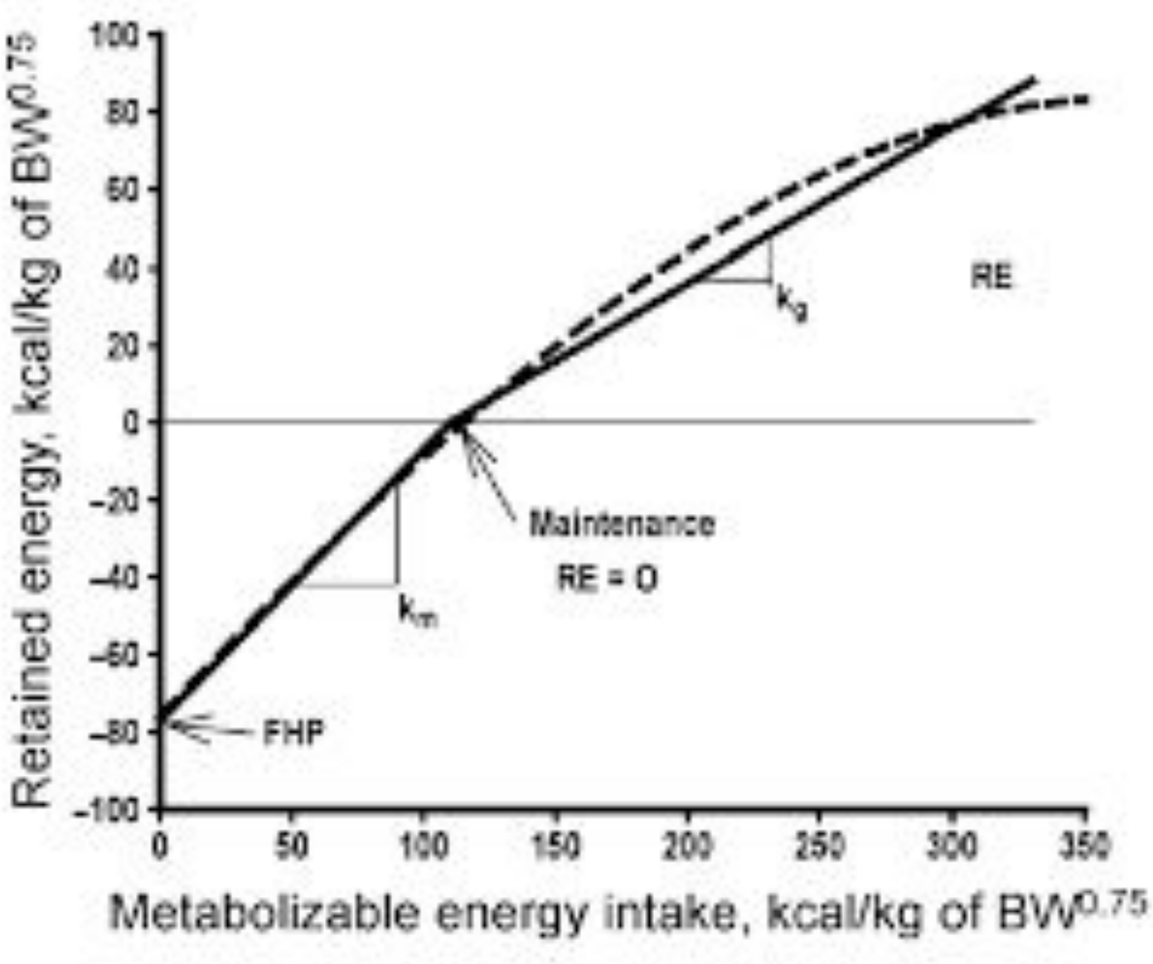
FIGURE 7–1 Relationship of dietary NE_m concentration to NE_m intake by beef cattle. Data points were obtained from published literature and represent treatment means for average intake during a feeding period.

$$DMI = SBW^{0.75} * (0.1493 * NE_m - 0.046 * NE_m^2 - 0.0196) \quad \text{Eq. 7-a}$$

Code

Source: NRC Beef Cattle (2000)

FHP, Maintanance, RE and k (Metab. Efficiency)



Maintenance = 0

$\neq$

$$dLW/dt \;= 0$$

$$NEm \;=\; ME\,.\,km \therefore km = NEm/ME$$
$$NEg \;=\; ME\,.\,kg$$

$$NE_m = 1.37 \cdot \mathrm{ME} - 0.138 \cdot \mathrm{ME}^2 + 0.0105 \cdot \mathrm{ME}^3 - 1.12$$
$$k_m = 1.37 - 0.138 \cdot \mathrm{ME} + 0.0105 \cdot \mathrm{ME}^2 - 1.12 \cdot ME^{-1}$$

Metabolizable energy utilization efficiency

BOX 11.6 Efficiency factors (k) used to describe the efficiency of metabolisable energy (ME) utilisation

k factor	Efficiency of ME utilisation for
k_m	Maintenance
k_p	Protein deposition
k_f	Fat deposition
k_g (or k_{pf})	Growth in general
k_l	Milk production
k_c	Foetal growth (the conceptus)
k_w	Work (e.g. in draught animals)
k_{wool}	Wool growth

Maintenance and body weight (Kleiber's law)

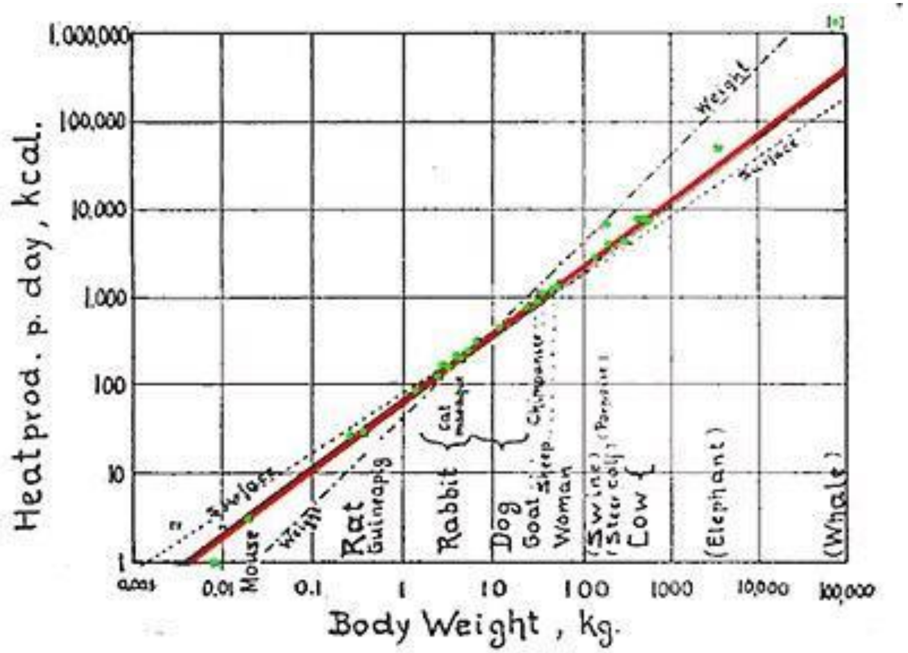
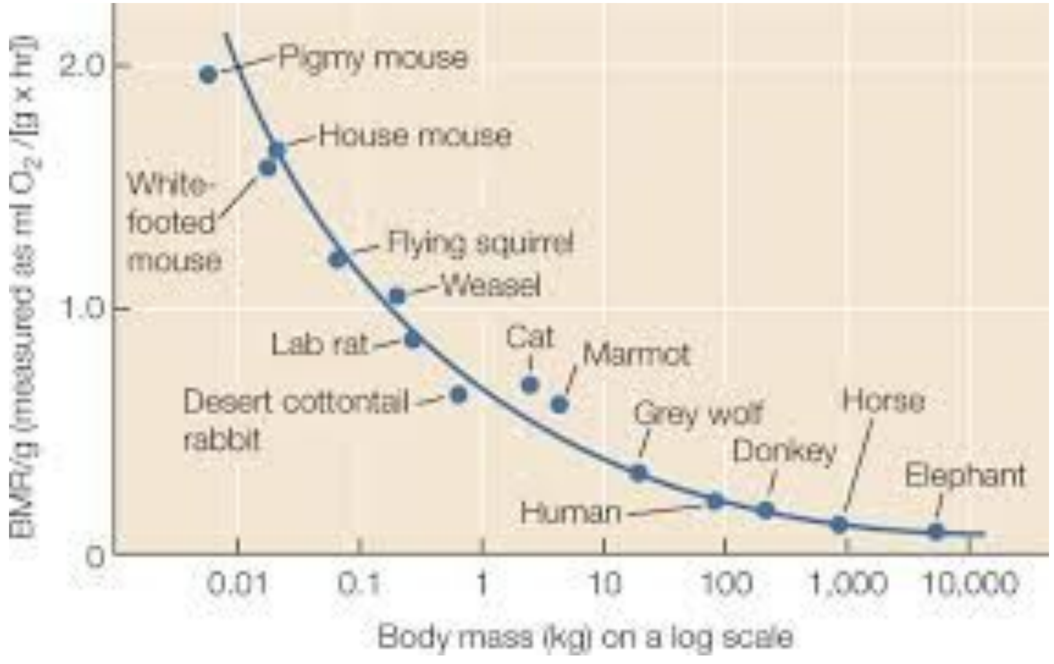


Fig. 1. Log. metabol. rate/log body weight



$$Maint = \alpha . EBW^{0.75} \qquad \alpha = 0.077 \left(\frac{Mcal}{EBW^{0.75}}\right)$$

Code

Breed Adjustments: Maintenance

Table 10–1 Breed Maintenance Requirement Multipliers, Birth Weights, Peak Milk Production[a]

Breed	Code	NE_m (BE)	Birth wt. kg (CBW)	Peak Milk Yield, kg / day (PKYD)
Angus	1	1.00	31	8.0
Braford	2	0.95	36	7.0
Brahman	3	0.90	31	8.0
Brangus	4	0.95	33	8.0
Braunvieh	5	1.20	39	12.0
Charolais	6	1.00	39	9.0
Chianina	7	1.00	41	6.0
Devon	8	1.00	32	8.0
Galloway	9	1.00	36	8.0
Gelbvieh	10	1.10	39	11.5
Hereford	11	1.00	36	7.0
Holstein	12	1.20	43	15.0
Jersey	13	1.20	31	12.0
Limousin	14	1.00	37	9.0
Longhorn	15	1.00	33	5.0
Maine Anjou	16	1.00	40	9.0
Nellore	17	0.90	32	7.0
Piedmontese	18	1.00	38	7.0
Pinzgauer	19	1.00	38	11.0

Estimating RE

$$\alpha = 0.077 \ (\frac{Mcal}{EBW^{0.75}})$$

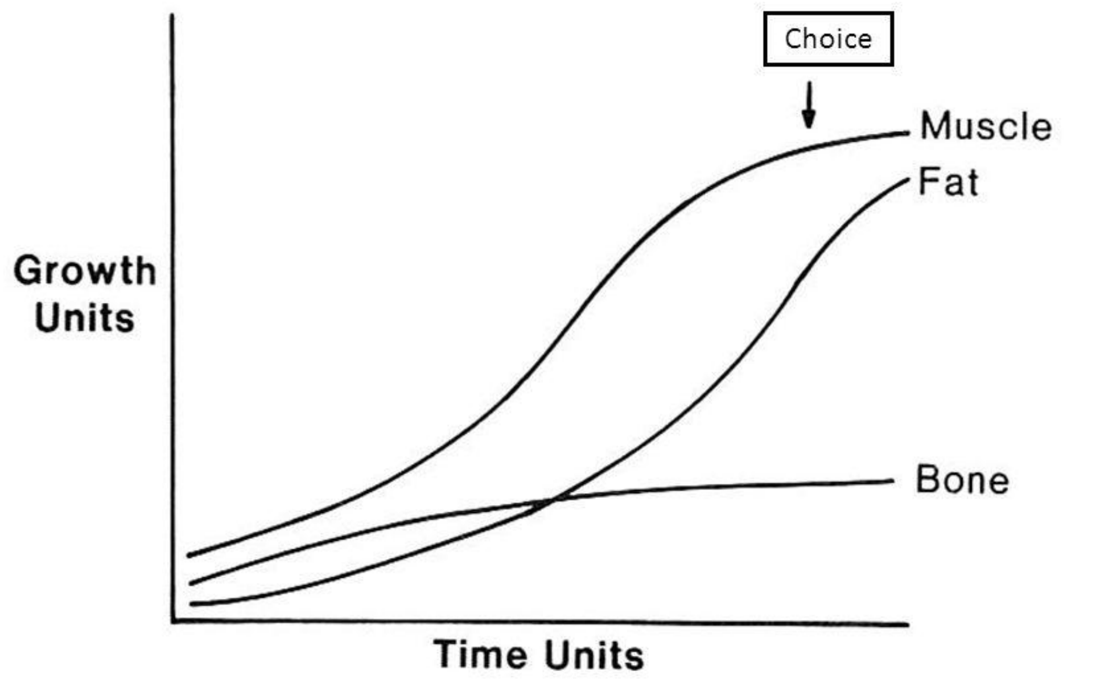
$$Maint = \alpha . EBW^{0.75}$$ # Energy Required for Maintenance (Mcal/d)

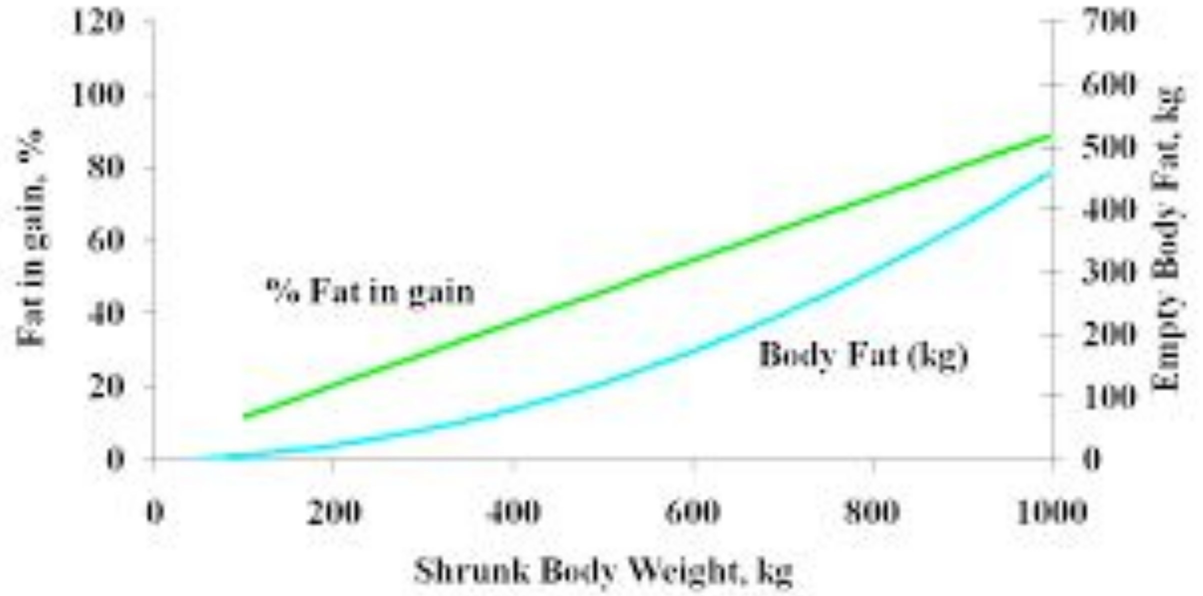
$$I_m = \frac{Maint}{NE_m}$$ # Dry Matter Intake Required for Maintenance (kg/d)

$$RE = (DMI - I_m) * NE_g = \left(DMI - \frac{\alpha . EBW^{0.75}}{NE_m} \right) * NE_g$$ # Retained Energy (Mcal/d)

Partition of Retained Energy

$$EBG = 12.341 * EQEBW^{-0.6837} * RE^{0.9116}$$

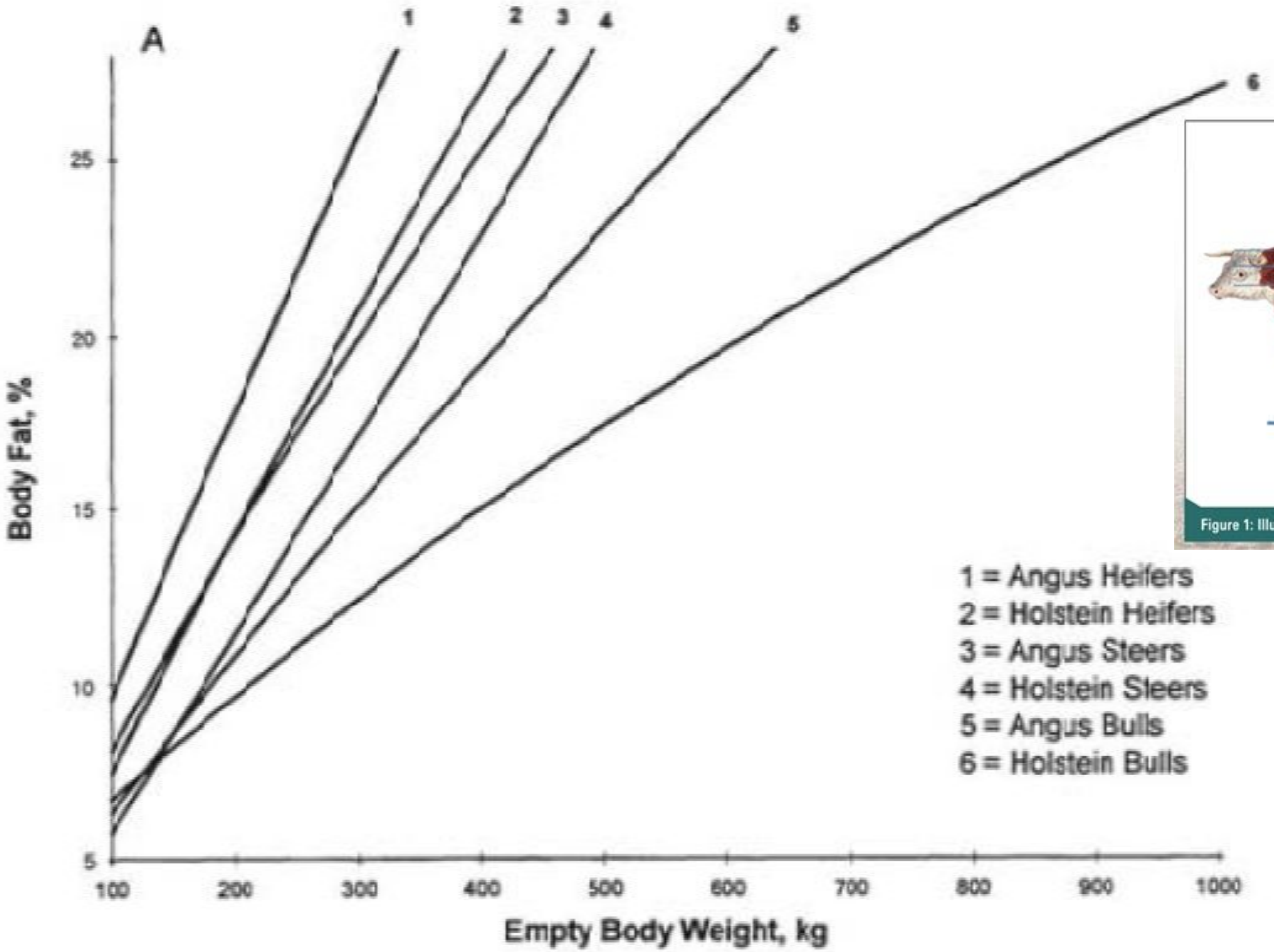




EPROT = 5.539 # Protein Energy Concentration
EFAT = 9.385 # Fat Energy Concentration
PROT.LEAN = 0.2201 # Proportion of protein in lean mass

https://doi.org/10.2527/jas.2011-5053

Adjusting partition for breed and gender



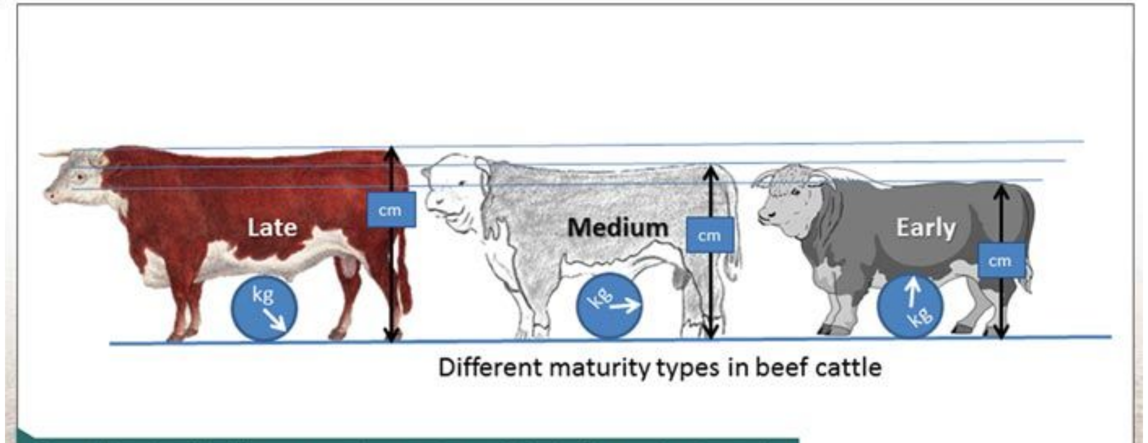


Figure 1: Illustration of the differences among three maturity types beef cattle of the same breed at maturity.

$$EQSBW = SBW * (SRW/FSBW)$$

EQSBW: Equivalent shrunk reference weight

SRW: shrunk reference weight

FSBW: Final shrunk reference weight

Source: NRC Beef Cattle (2000)

Feed Intake (NRC model)

TABLE 10–4 Adjustment Factors for Dry Matter Intake for Cattle[a]

Adjustment factor	Multiplier
Breed (BI)	
Holstein	1.08
Holstein × Beef	1.04
Empty body fat effect (BFAF)	
21.3 (to 350 kg EQW)	1.00
23.8 (400 kg EQW)	0.97
26.5 (450 kg EQW)	0.90
29.0 (500 kg EQW)	0.82
31.5 (550 kg EQW)	0.73
Anabolic implant (ADTV)	1.00
No anabolic stimulant	0.94
Temperature, °C (TEMP1)	
>35, no night cooling	0.65
>35, with night cooling	0.90
25 to 35	0.90
15 to 25	1.00
5 to 15	1.03
−5 to 5	1.05
−15 to −5	1.07
<−15	1.16
Mud (MUD1)	
None	1.00
Mild (10–20 cm)	0.85
Severe (30–60 cm)	0.70

[a]National Research Council, 1987.

For growing calves:

$$DMI = ((SBW^{0.75} * (0.2435NE_m - 0.0466NE_{ma}^2 - 0.1128))/NE_{ma}) * ((BFAF) * (BI) * (ADTV) * (TEMP1) * (MUD1)).$$

For diets with a $NE_m < 1.0$ Mcal/kg, NE_{ma} (divisor) = 0.95.

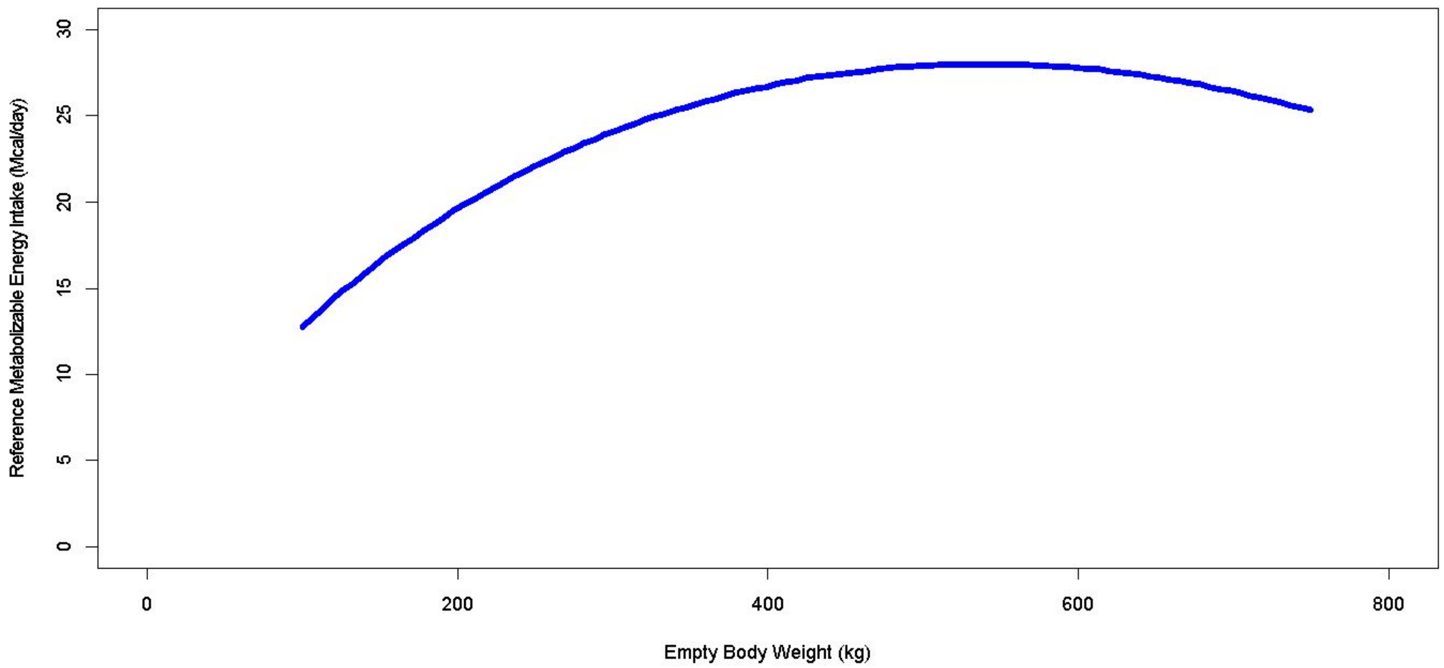
For growing yearlings:

$$DMI = ((SBW^{0.75} * (0.2435NE_{ma} - 0.0466NE_{ma}^2 - 0.0869))/NE_{ma}) * ((BFAF) * (BI) * (ADTV) * (TEMP1) * (MUD1)).$$

For diets with a $NE_m < 1.0$ Mcal/kg, NE_{ma} (divisor) = 0.95.

Source: NRC Beef Cattle (2000)

Feed Intake (Oltjen's model)



$$MEI_{norm} = \mathrm{EBW}^{0.75} \cdot \left(MEI_0 - MEI_1 * \frac{EBW}{EBWM} \right)$$

Source: Oltjen et al. (1986)

Empty Body Gain (NRC model)

$$EBG = 12.341 * EQEBW^{-0.6837} * RE^{0.9116}$$

Oltjen (1986) Model

$$\frac{\square}{\square} = \square \cdot \square \cdot (\square - \square) \quad (1)$$

$$\frac{\square}{\square} = \square \cdot \square \cdot \square^{0.73} - \square \cdot \square^{0.73} \quad (2)$$

$$\frac{\square}{\square} = \frac{\left(\square - \frac{\square}{\square}\right) * \left(\square - \frac{\square}{\square} \cdot \square\right)}{\square} \quad (3)$$

$$\mathrm{EBW} = \mathrm{F} + \frac{\mathrm{P}}{LEAN\_P}$$

State: D = DNA; P = Protein; F = Fat

Inputs: FI: Feed Intake; NEm: Feed net energy concentration for maintenance; NEg: Feed net energy concentration for gain

Auxiliary: M: Maintenance; ND: Energy restriction effect on DNA accretion; NP: Energy restriction effect on protein accretion

Parameters: Dmx = Maximum DNA mass; kD = speed of DNA accretion; kPs = Protein synthesis per g of DNA; kPd = Protein degradation per kg of protein

Constants: EP: Protein energy concentration of; EF : Fat energy concentration

DNA Dynamics

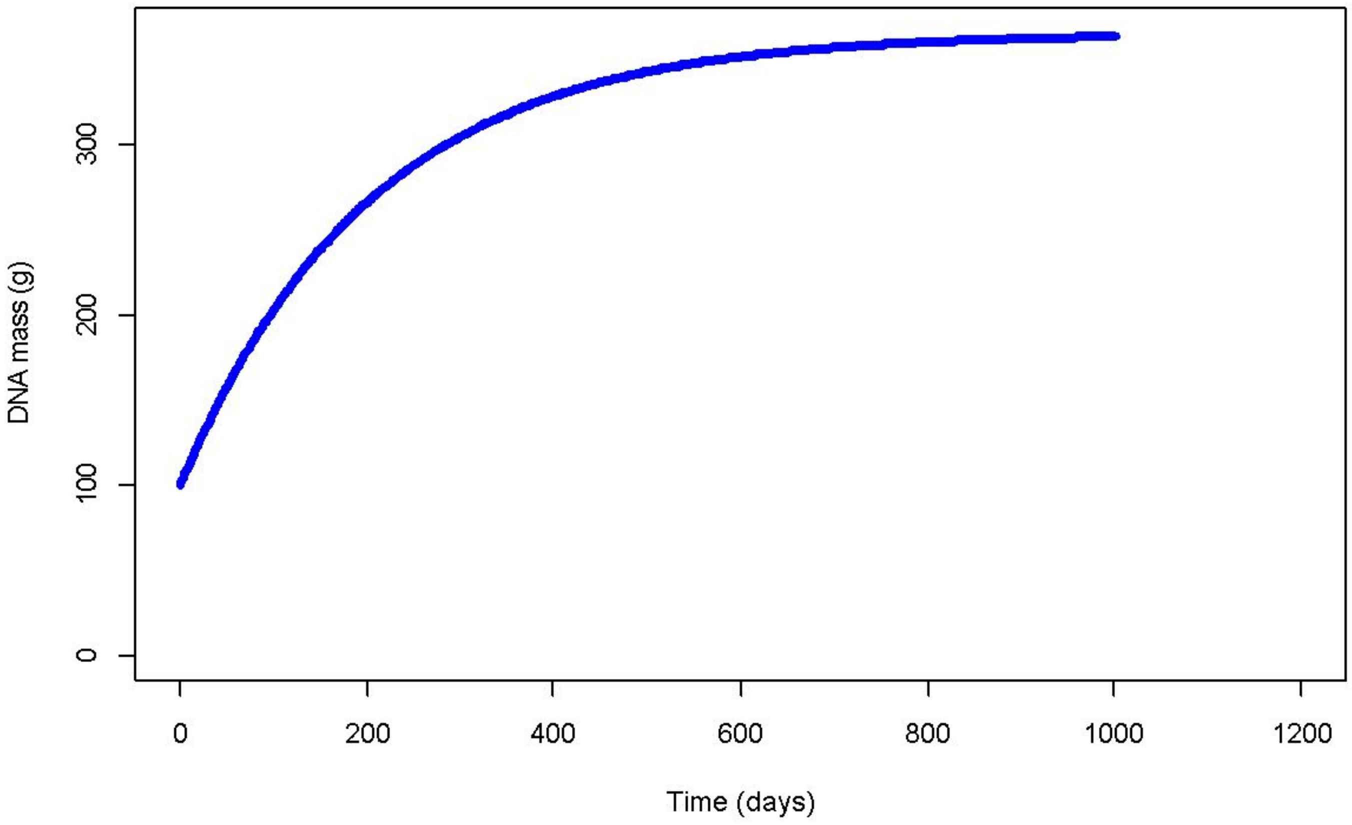
$$\frac{dD}{dt} = ND \cdot kD \cdot (Dmx - D)$$

$$ND = \beta_0 + \beta_1 \cdot \frac{\mathrm{MEI}}{\mathrm{MEI_{norm}}}$$

$$\mathrm{ER} = \frac{\mathrm{MEI}}{\mathrm{MEI_{norm}}}$$

$$ND = \beta_0 + \beta_1 \cdot ER$$

$$\beta_0 = -0.7$$
$$\beta_1 = \quad 1.7$$



DNA Dynamics

$$\frac{dD}{dt} = ND \cdot kD \cdot (D_{mx} - D)$$

$$\rho = ND \cdot kD$$

$$\frac{dD}{dt} = \rho \cdot (D_{mx} - D)$$

$$\frac{dD}{dt} = \rho \cdot Dmx \cdot (1 - \frac{D}{\mathrm{D_{mx}}})$$

$$\frac{dD}{\left(1 - \frac{D}{\mathrm{D_{mx}}}\right)} = \rho \cdot \mathrm{D_{mx}} \cdot dt$$

$$u = \left(1 - \frac{D}{\mathrm{D_{mx}}}\right);\ du = \frac{-dD}{\mathrm{D_{mx}}}$$

$$-\mathrm{D_{mx}} \int \frac{du}{u} = \rho \cdot \mathrm{D_{mx}} \int dt$$

$$-\int \frac{du}{u} = \rho \cdot \int dt$$

$$ln\left|1 - \frac{D}{\mathrm{D_{mx}}}\right| + K' = -\rho \cdot t$$

$$\exp\left(ln\left|1 - \frac{D}{\mathrm{D_{mx}}}\right| + k\right) = exp(-\rho \cdot t)$$

$$\left|1 - \frac{D}{\mathrm{D_{mx}}}\right| = \exp(-\rho \cdot t) \cdot \mathrm{k}$$

$$Para: D < \mathrm{D_{mx}}$$

$$\frac{D}{\mathrm{D_{mx}}} = 1 - \exp(-\rho \cdot t) \cdot \mathrm{k}$$

$$D = \mathrm{D_{mx}} - \mathrm{D_{mx}} \cdot \exp(-\rho \cdot t) \cdot \mathrm{k}$$

$$Fazendo: D = D_0\ para\ t = 0$$

$$\mathrm{D_0} = \mathrm{D_{mx}} - D^{*}\mathrm{k}$$

$$\mathrm{D_{mx}} \cdot \mathrm{k} = \mathrm{D_{mx}} - \mathrm{D_0}$$

$$\mathrm{k} = \frac{\mathrm{D_{mx}} - \mathrm{D_0}}{\mathrm{D_{mx}}}$$

$$\mathrm{k} = 1 - \frac{\mathrm{D_{mx}} - \mathrm{D_0}}{\mathrm{D_{mx}}}$$

DNA Dynamics

$$\left|1 - \frac{D}{\mathrm{D_{mx}}}\right| = \exp(-\rho \cdot t) \cdot \mathrm{k}'$$

$Para: D < \mathrm{D_{mx}}$

$$\frac{D}{\mathrm{D_{mx}}} = 1 - \exp(-\rho \cdot t) \cdot \mathrm{k}$$

$$D = \mathrm{D_{mx}} - \mathrm{D_{mx}} \cdot \exp(-\rho \cdot t) \cdot \mathrm{k}$$

$$D = \mathrm{D_{mx}} \cdot (1 - \exp(-\rho \cdot t) \cdot \mathrm{k})$$

$Fazendo: D = D_0 \; para \; t = 0$

$$\mathrm{D_0} = \mathrm{D_{mx}} - D^{*}\mathrm{k}$$

$$\mathrm{D_{mx}} \cdot \mathrm{k} = \mathrm{D_{mx}} - \mathrm{D_0}$$

$$\mathrm{k} = \frac{\mathrm{D_{mx}} - \mathrm{D_0}}{\mathrm{D_{mx}}}$$

$$\mathrm{k} = 1 - \frac{\mathrm{D_0}}{\mathrm{D_{mx}}}$$

$Substituindo \; k:$

$$D = \mathrm{D_{mx}} - \mathrm{D_{mx}} \cdot \exp(-\rho \cdot t) \cdot \left(1 - \frac{\mathrm{D_0}}{\mathrm{D_{mx}}}\right)$$

$$D = \mathrm{D_{mx}} - \exp(-\rho \cdot t) \cdot (\mathrm{D_{mx}} - \mathrm{D_0})$$

$$\boxed{\mathrm{D_{mx}} = \mathrm{D_0} + (\mathrm{D_{mx}} - \mathrm{D_0})}$$

$$D = \mathrm{D_{mx}} + (\mathrm{D_{mx}} - \mathrm{D_0}) - \exp(-\rho \cdot t) \cdot (\mathrm{D_{mx}} - \mathrm{D_0})$$

$$D = \mathrm{D_{mx}} + (\mathrm{D_{mx}} - \mathrm{D_0}) - (\mathrm{D_{mx}} - \mathrm{D_0}) \cdot \exp(-\rho \cdot t)$$

$$\boxed{D = \mathrm{D_0} + (\mathrm{D_{mx}} - \mathrm{D_0}) \cdot (1 - \exp(-\rho \cdot t))}$$

$$\boxed{Para \; D_0 = 0: \quad D = \mathrm{D_{mx}} \cdot (1 - \exp(-\rho \cdot t))}$$

Protein Dynamics

$$\frac{dP}{dt} = NP \cdot kPs \cdot D^{0.73} - kPd \cdot P^{0.73}$$

$$P^{0.73} = \frac{NP \cdot kPs \cdot D^{0.73} - \frac{dP}{dt}}{kPd}$$

$$Peq = \left(\frac{NP \cdot kPs \cdot D^{0.73} - \frac{dP}{dt}}{kPd}\right)^{1/_{0.73}}$$

$$Deq = \left(\frac{kPd \cdot P^{0.73} + \frac{dP}{dt}}{Np \cdot kPs}\right)^{1/_{0.73}}$$

$$kPs = 0.0444$$

$$kPd = 0.143$$

$$NP = \gamma_0 + \frac{\gamma_1 \cdot ER}{\gamma_2 + ER}$$

$$\gamma_0 = 0.83; \gamma_1 = 0.20; \gamma_2 = 0.15$$

$$\frac{dP}{dt} = NP \cdot kPs \cdot D^{0.73} - kPd \cdot P^{0.73}$$

$$P^{0.73} = \frac{NP \cdot kPs \cdot D^{0.73} - \frac{dP}{dt}}{kPd}$$

$$Peq = \left(\frac{NP \cdot kPs \cdot D^{0.73} - \frac{dP}{dt}}{kPd}\right)^{1/0.73}$$

$$Deq = \left(\frac{kPd \cdot P^{0.73} + \frac{dP}{dt}}{Np \cdot kPs}\right)^{1/0.73}$$

$$Pmx = \left(\frac{NP \cdot kPs \cdot Dmx^{0.73}}{kPd}\right)^{1/0.73}$$

$$Pmx = \left(\frac{NP \cdot kPs}{kPd}\right)^{1/0.73} \cdot Dmx$$

$$\theta = \left(\frac{NP \cdot kPs}{kPd}\right)^{1/0.73}$$

$$Pmx = \theta \cdot Dmx$$

NRC Static Model

$$\frac{dP}{dt} = NP \cdot kPs \cdot D^{0.73} - kPd \cdot P^{0.73}$$

$$kPs = 0.0444$$

$$kPd = 0.143$$

$$P^{0.73} = \frac{NP \cdot kPs \cdot D^{0.73} - \frac{dP}{dt}}{kPd}$$

$$Peq = \left(\frac{NP \cdot kPs \cdot D^{0.73} - \frac{dP}{dt}}{kPd}\right)^{1/0.73}$$

$$NP = \frac{\gamma_0 + \gamma_1 \cdot ER}{\gamma_2 + ER}$$

$$\gamma_0 = 0.83; \gamma_1 = 0.20; \gamma_2 = 0.15$$

$$Deq = \left(\frac{kPd \cdot P^{0.73} + \frac{dP}{dt}}{Np \cdot kPs}\right)^{1/0.73}$$

$$Pmx = \left(\frac{NP \cdot kPs \cdot Dmx^{0.73}}{kPd}\right)^{1/0.73}$$

$$Pmx = \left(\frac{NP \cdot kPs}{kPd}\right)^{1/0.73} Dmx$$

Fat Dynamics

$$\frac{dF}{dt} = \frac{\left(DMI - \frac{\alpha.EBW^{0.75}}{NE_m}\right) * NE_g \; - \frac{dP}{dt} \cdot EPROT}{EFAT}$$

$$\mathrm{EBW} = \mathrm{F} + \frac{\mathrm{P}}{LEAN\_P}$$

EPROT = 5.539 # Protein Energy Concentration
EFAT = 9.385 # Fat Energy Concentration
LEAN_P = 0.2201 # Proportion of protein in lean mass

Oltjen's Initialization

$$P = (\mathrm{EBW} - \mathrm{F}) \cdot LEAN\_P$$

$$F_p = (0.333{+}0.0833 \cdot \mathrm{BCS}) \cdot \frac{-54.6 + \mathrm{EQEBW}}{826 + \mathrm{EQEBW}}$$

$$P = \mathrm{EBW} \cdot \left(1 - F_p\right) \cdot LEAN\_P$$

$$Deq = \left(\frac{kPd \cdot P^{0.73} + \frac{dP}{dt}}{Np \cdot kPs}\right)^{1/0.73}$$

$$Deq = \left(\frac{kPd \cdot P^{0.73} + EBG \cdot P_{pig}}{Np \cdot kPs}\right)^{1/0.73}$$

$$P_{pig} = 0.248 - 0.0264 \frac{RE}{EBG}$$

$$Deq = \left(\frac{kPd \cdot P^{0.73} + 0.248 \cdot EBG - 0.0264 \cdot \mathrm{RE}}{Np \cdot kPs}\right)^{1/0.73}$$

$$RE = 0.0625 \cdot \mathrm{EQEB}W^{0.75} \cdot EBG^{1.097}$$