

*De Tilapiae Nutritione et Incremento*

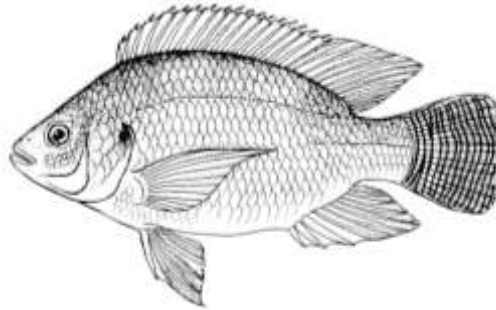
**Feeding and Growth Parameters of the Tilapia (*Oreochromis Niloticus*) in the body weight range from newly hatched larvae (about 5 mgrams) to about 700 grams**

*An overview of Data from the Literature and the Internet*

*Composit et Scripsit*

*Antonius H.M. Terpstra*

*Philosophiae Doctor Universitate Vadensi*



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*Orando, Laborando et Cogitando Patefiet Verum*

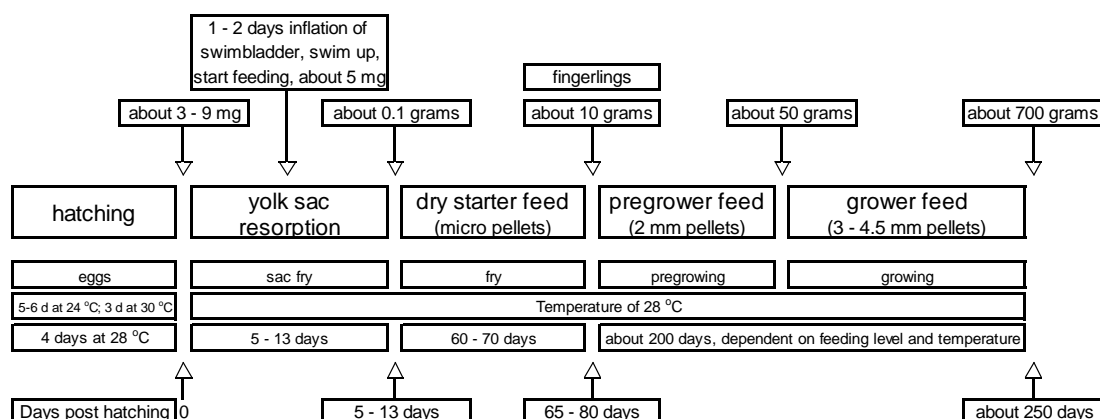
*Θαυμασια η αρχη της φιλοσοφιας (Plato)*

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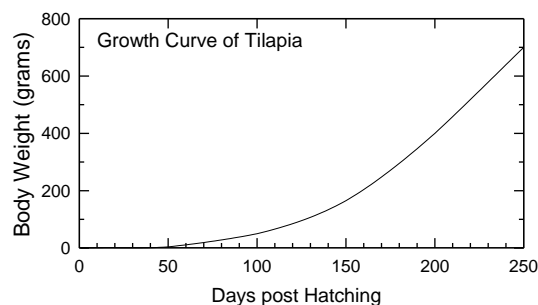
*The Netherlands, Anno Domini MMXV (2015).*

## Summary

### 1. Life cycle of the Tilapia.

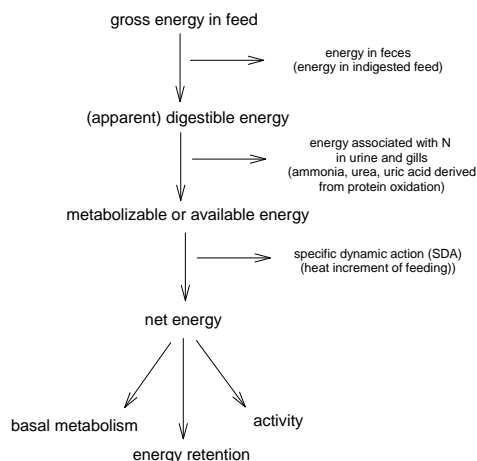


### 2. Typical growth curve of the Tilapia.



3. Tilapia feeds can be analyzed with the Weende analysis into the 5 major compounds, i.e. protein, fat, moisture, ash and fiber. The % protein and % fat are two major characteristics of fish feeds.

4. The energy in a Tilapia feed can be described in terms of (1) gross energy, (2) digestible energy, (3) metabolizable energy and (4) net energy.



5. The body composition of a Tilapia can be described by allometric equations of the form:  $y = a * BW(g)^b$ :

$$\begin{aligned} \text{Moisture (\%)} &= 75.40 \text{ BW(g)}^{-0.016} \\ \text{Fat (\%)} &= 5.87 \text{ BW(g)}^{0.095} \\ \text{Protein (\%)} &= 16.02 \\ \text{Ash (\%)} &= 4.28 \\ \text{Energy (kJ/g)} &= 5.98 \text{ BW(g)}^{0.041} \end{aligned}$$

$$\begin{aligned} \text{Moisture (g)} &= 0.754 \text{ BW(g)}^{0.984} \\ \text{Fat (g)} &= 0.0587 \text{ BW(g)}^{1.095} \\ \text{Protein (g)} &= 0.1602 \text{ BW(g)} \\ \text{Ash (g)} &= 0.0428 \text{ BW (g)} \\ \text{Energy (kJ)} &= 5.98 \text{ BW(g)}^{1.041} \end{aligned}$$

6. The feed intake in Tilapia can be described by allometric scaling formulae of the general form:  $y = a \cdot BW(kg)^b$  in two different ways:

- (a) as percentage of body weight (grams per 100 grams of fish per day) or
- (b) in grams per kg metabolic weight (per  $BW(kg)^{0.80}$ ) per day

The feed intake expressed in % of body weight can be converted into the feed intake expressed in grams per kg metabolic weight (per  $BW(kg)^{0.80}$ ) with the formula:

$$\text{Feed Intake in grams per kg metabolic weight} = c = 10 \cdot (\% \text{ feed intake per day}) / (BW(kg))^{-0.20} \quad (1)$$

and the feed intake expressed in grams per kg metabolic weight (c, per  $BW(kg)^{0.80}$ ) can be converted in the feed intake expressed as % of body weight with the formula:

$$\% \text{ feed intake per day} = (c/10) \cdot BW(kg)^{-0.20} \quad (2)$$

where c is the feed intake per kg metabolic weight (per  $BW(kg)^{0.80}$ ).

Both ways of expressing the feed intake can be described by allometric scaling formulas of the general form  $a \cdot BW(kg)^b$  where the feed intake (either as % of body weight or as grams per kg metabolic weight (per  $BW(kg)^{0.80}$ )) is a function of the body weight. The % feed intake can be described by the allometric scaling formula:

$$\% \text{ feed intake} = a \cdot BW(kg)^b \quad (3)$$

And subsequently converting this formula into grams per kg metabolic weight (per  $BW(kg)^{0.80}$ ) with formula (1) gives:

$$\text{feed intake in grams per kg metabolic weight} = 10 \cdot a \cdot BW(kg)^{(b + 0.20)} \quad (4)$$

A typical value for b = - 0.350 and a typical value for "a" = 1.4 for Tilapia at a temperature of 27 - 29 °C. Thus:

$$\% \text{ feed intake} = 1.4 \cdot BW(kg)^{-0.350} \quad (5)$$

and expressed in grams per kg metabolic weight with formula (1):

$$\text{feed intake in grams per kg metabolic weight} = 14 \cdot BW(kg)^{-0.150} \quad (6)$$

At this feeding level, the % feed intake ranges from 7% for a Tilapia of 10 grams to 1.6% for a Tilapia of 700 grams and the feed intake per gram metabolic weight (per  $BW(kg)^{0.80}$ ) ranges from 28 grams for a Tilapia of 10 grams to 15 grams for a Tilapia of 700 grams.

These feeding curves involve that the feed intake per kg metabolic weight (per  $BW(kg)^{0.80}$ ) and thus also the ratio of metabolizable energy for production / metabolizable energy for maintenance (Mp/Mm) decreases when the body weight of the Tilapia increases. These feeding levels (at 27 - 29 °C) are comparable with the feeding levels as recommended by various fish feed manufacturers. Lower or higher feeding levels can be obtained by decreasing or increasing the value of "a".

7. The criteria for a good performing Tilapia feed (or a good Tilapia feed ingredient) can be summarized with the 4 P 's concept:

- |    |                     |  |
|----|---------------------|--|
| 1. | <b>Palatability</b> | Attractive feed to assure a high feed intake.                              |
| 2. | <b>Performance</b>  | A good feed conversion ratio FCR or feed efficiency ratio (FER).           |
| 3. | <b>Pollution</b>    | High digestibility and faeces that are compact and thus easily to collect. |
| 4. | <b>Price</b>        | The price should be right and the feed should be cost effective.           |

## Contents

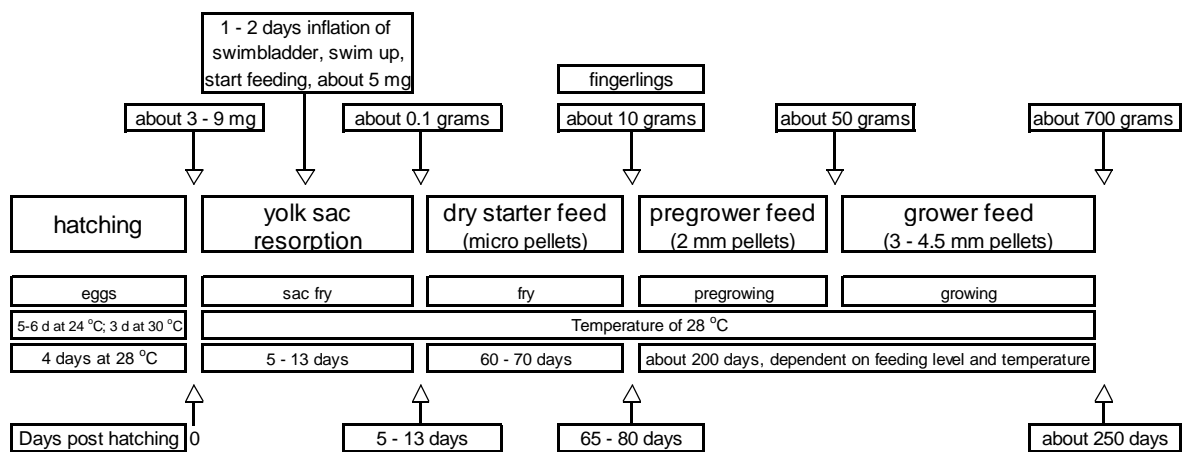
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	Page
1. Life cycle of the Tilapia	5
2. The composition of Tilapia feeds	8
3. Energy in Tilapia feeds	9
4. Feed sizes for Tilapia	11
5. Feed intake and feeding levels	11
6. Feed intake and feeding levels from the Internet	13
7. Construction of a general feeding curve for Tilapia	19
8. Growth curves for Tilapia	21
9. Body composition of Tilapia	27
10. Factors that affect the performance of a Tilapia feed: the 4 P's concept	28
11. Literature	30
12. Production cycle of the Tilapia (FAO data)	31
13. Energy values of fats, proteins and carbohydrates	32
14. Properties of logarithms	35

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## 1. Life Cycle of the Tilapia (*Oreochromis niloticus*)



**Figure 1**  
 Life cycle of the Tilapia

The aquaculture of the Tilapia goes back to the ancient Egypt. The tilapia is a cichlid fish of African origin and the Latin name of the Nile Tilapia is *Oreochromis Niloticus*. The optimum temperature for the Tilapia is about 27 – 30 °C.



**Figure 2**  
 Eggs of Tilapia (mouth breeder)

The eggs of the tilapia are yellowish and pear shaped and have a relatively large size (3 – 3.4 and 2.2 – 2.5 mm). They hatch after about 4 – 7 days (depending on the temperature, see Table 1 and 2 below) and the weight of the newly hatched tilapia larvae is about 3 – 9 mg (3 – 5 mm). It takes about 5 – 13 days to absorb the yolk sac. The tilapia can already be fed with dry feed at about 2 days after hatching (when the fry start to swim up and de swim bladder starts to develop).

The Tilapia feeds low on the feed chain and feeds on phyto- and zooplankton. The digestive system of the tilapia is rather long (see Figure 6 below), which is characteristic for omnivorous or herbivorous animals.

**Table 1**  
 Life cycle of tilapia larvae

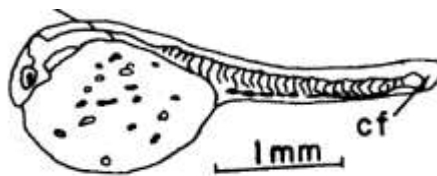
Period	hours	days (after incubation)	days (after hatching)
Hatching	90 - 102	4 - 5	
Swim up fry	120 - 144	5 - 6	1 - 2
End of yolk sac	216 - 432	9 - 18	5 - 13

Source: FAO on the internet: Selected aspects of warm water cultured fish species: Tilapias and their culture fish.  
 (Accessed in 2014)

**Table 2**  
 Incubation time of the tilapia eggs

Temperature °C	Incubation Time in Days
24	5 - 6
28	4
30	3
34	2

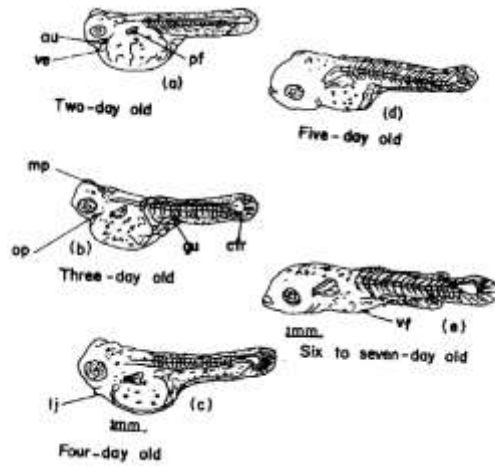
Source: FAO on the internet: Selected aspects of warm water cultured fish species: Tilapias and their culture fish.  
 (Accessed in 2014)



**Figure 3**

One day old larva of the *Tilapia zillii*

From: Omotosho et al. *Nigerian Journal of Science* 22: 24-28 (1988)

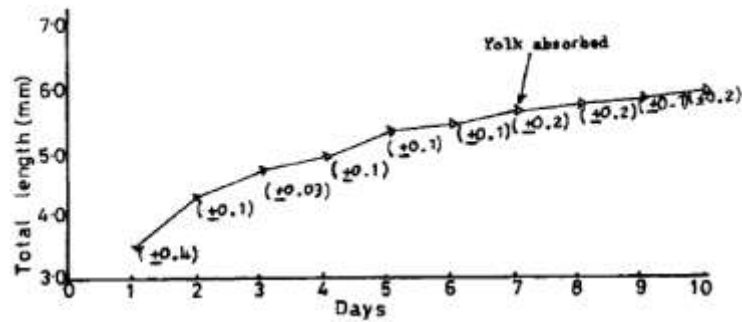


**Figure 4**

Larvae of various days old (*Tilapia zillii*)

From: Omotosho et al. Nigerian Journal of Science 22: 24-28 (1988)

(pf = pectoral fins; au, auricle; ve, ventricule; mp, melanophore; op, operculum; gu, gut; cfr, caudal fin ray; vf, ventral fins.



**Figure 5**

Length of larvae of various days old (*Tilapia zillii*)

From: Omotosho et al. Nigerian Journal of Science 22: 24-28 (1988)



**Figure 6**

Length of the intestines of a tilapia

. Retrieved in 2010.

## 2 The Composition of Tilapia Feeds

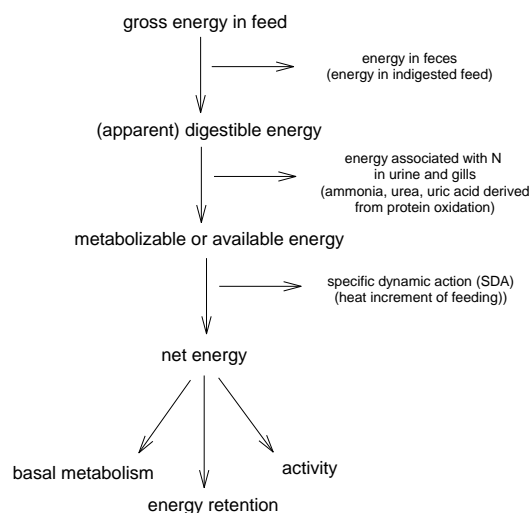
Around the year 1860, the researchers Henneberg and Stohmann at the Agricultural Research Institute in Weende in Germany proposed to partition animal feeds into six major compounds, i.e. (1) moisture, (2) protein, (3) fat, (4) ash, (5) crude fibre and the so called (6) nitrogen free extract (NFE). The moisture, protein, ash and fibre were measured and the NFE was calculated as the difference between the total amount of the feed and these five measured compounds. This so-called Weende analysis is still being used for the analysis of (fish) feeds and foods.

Fish feeds are mostly characterized by their protein and fat levels and the ratio of protein / energy (mg protein / kJ energy). The protein in the feed is primarily needed for the build-up of (muscle) tissues and the fat is a major source of energy and for accretion of fat tissue. Protein drives the growth but there is a maximum amount of protein that can be deposited per day. Thus, it is important that sufficient protein (and protein with the right amino acid composition) is taken up to achieve this maximum protein deposition and growth. On the other hand, the intake of excess of protein that exceeds the maximum capacity to deposit the protein, and also excess of energy will result in the deposition of fat and result in fatty fish. Thus, the right ratio of energy to protein and the right amount of feed is important for optimal growth and Tilapia composition.

The digestible protein / digestible energy ratio is thus an important characteristic of a fish feed, and as a rule of thumb, this ratio in the trout feed (for growing Tilapia) should be approximately similar to the ratio of protein / energy of the fish itself. This way, a maximal retention of dietary protein, an expensive ingredient of trout feed, is achieved. When the trout grows larger, the protein / energy ratio of the trout becomes lower (the percentage fat of the fish increases whereas the percentage protein remains the same), and as a consequence, the ratio protein / energy in the diet should also decrease in order to maintain a maximum protein retention. This phenomenon is called phase feeding or the protein sparing effect of fat.

## 3 Energy in Tilapia Feeds

Fats, carbohydrates and proteins are the major sources of energy in Tilapia feeds. The energy density of these three compounds is different and the amount of energy in a Tilapia feed is related to the amount of fat, carbohydrates and proteins in the feed. The energy in a trout feed can be expressed as gross, digestible and metabolizable energy (Figure 8).





## Figure 8

Gross, digestible, metabolizable, and net energy

### **Gross Energy**

The gross energy is the energy or heat that is generated when the feed is completely oxidized. The law of the German Hess (1838) states that the heat produced in a chemical reaction is always the same regardless of whether it proceeds directly or via a number of intermediate steps (the law of constant heat summation). It means effectively that the heat of metabolizing a nutrient through a complex web of metabolic reactions in the body may be determined and duplicated by measuring the heat produced by burning the same nutrient in a bomb calorimeter. The gross energy can thus be determined by complete combustion of the feed in a so called bomb calorimeter and by measuring the amount of energy or heat that is released. This way, the amount of gross energy can be determined in a complete feed or in only fat, carbohydrates or proteins (Table 3 and 4).

### **Digestible Energy**

The digestible energy is the amount of gross energy in the feed that is digested and is taken up by the fish. The digestibility of fat, carbohydrates and proteins is different and is dependent on various factors. Some raw materials are better digested than others and also the feeding level plays a role; a higher feed intake results usually in a lower digestion of the feed. The average digestibilities are given in Table 3 and are generally used to calculate the digestible energy in a fish feed.

### **Metabolizable Energy**

The metabolizable energy is the energy in the feed that the Tilapia can actually utilize. Metabolizable energy is the digested energy that the body can use and is available to the body. The (gross) energy of the digested carbohydrates and fat are completely available for the body. The fish can completely oxidize the fat and carbohydrates to generate energy. The metabolizable energy of fat and carbohydrates would be equal to the gross energy when fat and carbohydrates would be completely digested. Proteins, on the other hand, contain nitrogen and the nitrogen that is released during the oxidation of proteins as ammonia can only be excreted by the fish in the form of ammonia and urea (Figure 8). About 85% of the released nitrogen is excreted as ammonia through the gills and about 15% as urea in the urine. Ammonia and urea contain substantial amounts of energy, i.e. ammonia has an energy density of 20.7 kilojoule (kJ) per gram and urea an energy density of 10.8 kJ per gram. This means that the fish can not completely use the gross energy in the proteins. The energy excreted in ammonia (85%) and urea (15%) is 3.98 kJ per gram protein and the metabolizable or available energy is then  $23.65 - 3.98 = 19.67$  kJ per gram protein. Protein contains 23.65 kJ gross energy per gram and the fish can thus only use 19.67 kJ per gram protein (see paragraph 13, footnote 6 (g) for the calculations in the fish).

### **Net Energy**

The processing of the nutrients after digestion (storage, deamination, synthesis, such as synthesis of urea and uric acid, etc.) requires energy and this energy is called the specific dynamic action (SDA) or the thermic effect of feed or food (TEF). The net energy is the metabolizable energy corrected for the energy of the SDA. Net energy is thus the energy that can eventually be used for the maintenance, activity and growth.

## Table 3

## Energy values of various dietary compounds as used in fish nutrition.

	Gross Energy in 1 gram nutrient (kJ/gram)	Metabolizable Energy in 1 gram nutrient (kJ/gram)	Digestibility (%)	Digestible energy In feed (kJ/gram nutrient)	Metabolizable energy In feed (kJ/gram nutrient)
Crude Fat	39.60	39.60	90 (90-95)	35.64	35.64
Crude Protein	23.65	19.67	95 (85-95)	22.50	18.69
NFE or Carbohydrates	17.50	17,50	70 (40-90)	12.25	12,25
Fiber and Cellulose	17.50	17,50	0	0	0

The metabolizable energy in 1 gram of fat or carbohydrate is similar to the gross energy in 1 gram of fat or carbohydrate. However, the metabolizable energy in 1 gram of protein is the gross energy (23.65 kJ) minus the energy that is excreted into the urine in the form of ammonia (85%) and urea (15%) (a total of 3.98 kJ, see paragraph 13, footnote 6 (g), thus 23.65 – 3.98 = 19.67 kJ). The values for gross energy and for the metabolizable energy in 1 gram nutrient can be used for all fish species. However, the values for the digestibilities (and thus the values for the digestible and metabolizable energy in the feed) may vary and is dependent on the type of the diet and the fish species.

Fish metabolize and oxydize predominantly fat and proteins and the average energy equivalent of oxygen (Eq O<sub>2</sub>) for fat (13.72 kJ per gram oxygen) and for protein (13.79 per gram oxygen in ammoniatic fish) (see page 33, paragraph 13) is about 13.75 kJ per gram oxygen. Thus, the energy expenditure or heat production of the fish in kJ can be calculated by multiplying the oxygen uptake (grams) of a fish by 13.75.

### Calculation of the energy in a Tilapia feed

The amount of energy in a Tilapia feed (Table 4) can be easily calculated with the data in Table 3. The percentages of fat, protein, ash and fibre are usually declared on the label on the bag of the Tilapia feed and the percentage of moisture is usually about 4 - 8%. The percentage of carbohydrates (also called the nitrogen free extract, or NFE) is calculated as (100 - % protein - % fat - % ash - % fibre - % moisture). Table 4 gives as example of a Tilapia feed with 35% protein, 8% fat, 7% ash and 6 % fibre. Thus the percentage of carbohydrates or NFE = (100 – 35% protein – 8% fat - 7% ash – 6.0% fibre – 8.2% moisture) = 35.8%.

Energy is usually expressed in joules (J) or kilojoules (kJ; 1 kJ = 1000 joules). Sometime, energy is also expressed in calories (cal) or kilocalories (kcal); 1 cal = 4.184 joule. In the metric system and in science only joules are used.

**Table 4**  
Composition of a typical Tilapia feed

Nutrient	% in diet	Gross Energy in 1 gram nutrient (kJ/gram)	Metabolizable Energy in 1 gram nutrient (kJ/gram)	Gross Energy in 1 gram feed (kJ/gram)	Digestibility (%)	Digestible Energy in 1 gram feed (kJ/gram)	Metabolizable Energy in 1 gram feed (kJ/gram)
Protein	35,00	23,65	19,67	8,28	95,00	7,86	6,54
Fat	8,00	39,60	39,60	3,17	90,00	2,85	2,85
Ash	7,00						
Moisture	8,20						
Fiber	6,00	17,50	0,00	1,05	0,00		
NFE	35,80	17,50	17,50	6,27	60,00	3,76	3,76
Total	100,00			18,76		14,47	13,17

NFE, nitrogen free extract, the carbohydrate faction. DP/DE (digestible protein/digestible energy) = (350\*0.95)/14.47 = 22.97 mg/kJ

## 4 Feed Sizes for Tilapia

The size of the feed is dependent on the body weight and body length of the Tilapia. The feed sizes as recommended by the FAO and the fish feed manufacturers Coppens International and Biomar are given in Table 5.

**Table 5**  
 Feed Sizes for the Tilapia

FAO (2014)			Coppens Website (2014)		Biomar Website (2014)	
Fish Length (cm)	Fish Weight (grams)	Feed Size (mm)	Fish Weight (grams)	Feed Size (mm)	Fish Weight (grams)	Feed Size (mm)
0,3 - 0,4	0,003 - 0,005	0.1 – 0.2	0.005 – 0.1	0,2 - 0,3		
1 - 2	0,05 - 0,25	0,25 - 0,5				
2 - 3	0,25 - 0,5	0,5 - 0,75	0,1 - 0,35	0,3 - 0,5		
3 - 4	0,5 - 1	0,75 - 1	0,35 - 1	0,5 - 0,8	not given	0.4
4 - 5	1 - 3	1 - 2	1 - 2,5	0,8 - 1,2	not given	0.6
			2,5 - 6	1,2 - 1,5	not given	1
			6 - 10	1,5	4 - 8	1.5
5 - 9	3 - 30	2 - 3	10 - 15	1,5/2,0	8 - 25	1.9
	30 - 100	2	15 - 35/70	2 - 2/3	25 - 60	3
	100 - 250	3	70 - 200/300	3 - 3/4,5	60 - 400	4.5
	250 -	4	300 - 500	4,5		
			> 500	4,5/6,0		

From the website of the FAO: *Source:* FAO on the internet: Selected aspects of warm water cultured fish species: Tilapias and their culture fish (accessed in 2014); the website of Coppens international, [www.coppens.eu](http://www.coppens.eu) (accessed in 2014) and the website of Biomar, [www.biomar.com](http://www.biomar.com) (accessed in 2014).

## 5 Feed Intake and Feeding Levels

For details on the background and derivations of the formulas of feed intake and feeding level curves in general, the reader is referred to the article: “feeding and growth parameters of the trout” (Paragraph 6).

### In summary:

The feed intake in Tilapia can be expressed in two different ways:

- (1) as percentage of body weight per day or
- (2) in grams per kg metabolic weight (per  $BW(kg)^{0.80}$ ) per day

The feed intake expressed in % of body weight can be converted into the feed intake expressed in grams per kg metabolic weight (per  $BW(kg)^{0.80}$ ) with the formula:

$$\text{Feed Intake per kg metabolic weight} = c = 10 * (\% \text{ feed intake per day}) / (BW(kg)^{-0.20}) \quad (1)$$

and the feed intake expressed in grams per kg metabolic weight (c, per  $BW(kg)^{0.80}$ ) can be converted in the feed intake expressed as % of body weight with the formula:

$$\% \text{ feed intake (or feed intake per 100 gram of fish)} = (c/10) * BW(kg)^{-0.20} \quad (2)$$

where c is the feed intake in grams per kg metabolic weight (per kg BW(kg)<sup>0.80</sup>).

Both ways of expressing the feed intake can be described by allometric scaling formulas of the general form  $a * BW(kg)^b$  where the feed intake (either as % of body weight or as grams per kg metabolic weight (per BW(kg)<sup>0.80</sup>) is a function of the body weight. The % feed intake can be described by the allometric scaling formula:

$$\% \text{ feed intake} = a * BW(kg)^b \quad (3)$$

And subsequently converting this formula into grams per kg metabolic weight (per (BW(kg)<sup>0.80</sup> with formula (1) gives:

$$\text{feed intake per kg metabolic weight} = 10 * (a * BW(kg)^b) / (BW(kg)^{-0.20}) \text{ or}$$

$$\text{feed intake per kg metabolic weight (per kg BW(kg)}^{0.80}) = 10 * a * BW(kg)^{(b + 0.20)} \quad (4)$$

**Example:**

We have the following feeding curve expressed in % of body weight:

$$\% \text{ feed intake} = 1.5 * BW(kg)^{-0.250}$$

The % feed intake of a fish of 350 grams is:  $1.5 * (0.350)^{-0.250} = 1.95$

The total feed intake for a fish of 350 grams is:  $0.0195 * 350 = \mathbf{6.83 \text{ grams}}$

The feed intake expressed in grams per kg metabolic weight (per BW(kg)<sup>0.80</sup>) is:

$$\text{Feed intake (grams) per BW(kg)}^{0.80} = 1.5 * 10 * BW(kg)^{(-0.250 + 0.20)} \text{ or}$$

$$\text{Feed intake (grams) per BW(kg)}^{0.80} = 15.0 * BW(kg)^{-0.050}$$

The feed intake in grams per kg metabolic weight for a fish of 350 grams is:  $15 * (0.350)^{-0.050} = 15.81$

The total feed intake for a fish of 350 grams is :  $15.81 * (0.350)^{0.80} = \mathbf{6.82 \text{ grams}}$

## 6 Feed Intake and Feeding Levels from the Internet

Feeding levels and feeding tables for Tilapia are given by various feed manufacturers such as Coppens, Zemach and Biomar and other institutions such as the FAO and the SRAC in the USA. These feeding tables are given in the Tables 6 through 10.

**Table 6**  
The Coppens Feeding Table for Tilapia from the Internet (2014)

Body weight (grams)			Feed Intake	Feed Intake	Feed Size
Initial	Final	Average	% of body weight	g/BW(kg) <sup>0.80</sup>	(mm)
0,005	0,1	0,05	9	12,54	0,2-0,3
0,10	0,35	0,23	8,5	15,84	0,3-0,5
0,35	1,00	0,68	8	18,58	0,5-0,8
1,00	2,50	1,75	7	19,67	0,8-1,2

2,60	6,00	4,3	6	20,18	1,2-1,5
6,0	10,0	8,0	5,5	20,94	1,5
10	15	12,5	5	20,81	1,5-2,0
15	30	22,5	4,5	21,07	2
30	40	35	4	20,46	2
40	50	45	3,7	19,90	2
50	70	60	3,3	18,80	2
70	100	85	2,9	17,71	3
100	150	125	2,5	16,49	3
150	200	175	2,2	15,52	3
200	300	250	2,0	15,16	3
300	400	350	1,9	15,40	3
400	500	450	1,7	14,49	4,5
500	600	550	1,5	13,31	4,5
600	700	650	1,4	12,84	4,5
700	800	750	1,3	12,27	4,5
800	900	850	1,2	11,62	4,5

From the website of Coppens International, [www.coppens.eu](http://www.coppens.eu) (accessed in 2014) Water temperature of 27 °C. The feeding level expressed in % feed intake were converted into grams per kg metabolic weight (per BW(g)<sup>0.80</sup>) with the formula: Feed intake per kg metabolic weight (per BW(kg)<sup>0.80</sup>) = 10 \* (% feed intake per day) / (BW(kg)<sup>-0.20</sup>).

**Table 7**  
 The Biomar Feeding Tabel for Tilapia from the Internet (2014)

Body Weight (grams)			Feed Intake as % of body weight									
			Water Temperature (°C)									
Initial	Final	average	17	19	21	23	25	27	29	31	33	
4	8	6	1,72	2,51	3,45	4,31	5,22	7,01	6,91	3,54	1,56	
8	15	11,5	1,77	2,66	3,4	4,25	4,67	7,64	6,78	3,5	1,54	
15	25	20	1,63	2,53	3,26	4,07	4,26	7,41	6,48	3,35	1,47	
25	35	30	1,58	2,38	3,16	3,95	4,17	7,1	6,39	3,25	1,43	
35	60	47,5	1,34	2,06	2,68	3,34	3,62	5,53	4,99	2,75	1,21	
60	100	80	1,23	1,85	2,46	3,08	3,31	3,63	3,2	2,53	1,12	
100	160	130	1,06	1,58	2,11	2,64	2,84	2,91	2,74	2,17	0,96	
160	300	230	0,9	1,35	1,8	2,25	2,42	2,48	2,33	1,85	0,81	
300	400	350	0,76	1,14	1,52	1,9	2,04	2,09	1,97	1,56	0,69	

Body Weight (grams)			Feed Intake in grams per kg metabolic weight (per BW(kg) <sup>0.80</sup> )									
			Water Temperature (°C)									
Initial	Final	average	17	19	21	23	25	27	29	31	33	
4	8	6	6,18	9,02	12,40	15,49	18,76	25,20	24,84	12,72	5,61	
8	15	11,5	7,25	10,89	13,92	17,40	19,12	31,28	27,76	14,33	6,30	
15	25	20	7,45	11,57	14,91	18,61	19,48	33,89	29,63	15,32	6,72	
25	35	30	7,84	11,80	15,67	19,59	20,68	35,21	31,69	16,12	7,09	
35	60	47,5	7,29	11,20	14,57	18,16	19,68	30,07	27,13	14,95	6,58	
60	100	80	7,42	11,16	14,84	18,59	19,97	21,90	19,31	15,27	6,76	
100	160	130	7,05	10,51	14,03	17,55	18,88	19,35	18,22	14,43	6,38	
160	300	230	6,71	10,06	13,42	16,77	18,04	18,48	17,37	13,79	6,04	
300	400	350	6,16	9,24	12,32	15,40	16,54	16,94	15,97	12,65	5,59	

From the Biomar website, [www.biomar.com](http://www.biomar.com) (accessed in 2014). The feeding levels expressed in % feed intake were converted into grams per kg metabolic weight (per BW(g)<sup>0.80</sup>) with the formula: Feed intake per kg metabolic weight (per BW(kg)<sup>0.80</sup>) = 10 \* (% feed intake per day) / (BW(kg)<sup>-0.20</sup>).

**Table 8**  
 The Feeding Table of Zemach Israel for Tilapia (2014)

Age Days	Period Days	Average Days	Body Weight (grams)	Feed Intake % of body weight	Feed Intake g/BW(kg) <sup>0,80</sup>	SGR % BW/day	Cumulative FCR
1	1 - 10	5	0,5	30	65,60	18,68	
10	10 - 20	15	3,2	8,3	26,31	8,5	0,46
20	20 - 30	25	7,6	5,3	19,97	5,92	0,55
30	30 - 40	35	13,7	4,7	19,93	4,55	0,6
40	40 - 50	45	21,6	4,4	20,43	3,7	0,68
50	50 - 60	55	31,3	4,2	21,01	3,12	0,77
60	60 - 70	65	42,7	3,7	19,69	2,7	0,87
70	70 - 80	75	56	3,6	20,23	2,38	0,95
80	80 - 90	85	71	3,5	20,62	2,12	1,03
90	90 - 100	95	87,8	3,3	20,29	1,92	1,12
100	100 - 110	105	106,4	3,2	20,44	1,75	1,19
110	110 - 120	115	126,7	3,1	20,51	1,61	1,27
120	120 - 130	125	148,9	2,9	19,81	1,49	1,35
130	130 - 140	135	172,8	2,6	18,30	1,39	1,41
140	140 - 150	145	198,5	2,4	17,37	1,30	1,45
150	150 - 160	155	226	2,3	17,08	1,22	1,49
160	160 - 170	165	255,2	2,2	16,74	1,15	1,52
170	170 - 180	175	286,3	2,1	16,35	1,09	1,55
180	180 - 190	185	319,1	1,9	15,12	1,03	1,58
190	190 - 200	195	353,7	1,8	14,62	0,98	1,6
200	200 - 210	205	390,1	1,7	14,08	0,93	1,61
210	210 - 220	215	428,2	1,7	14,35	0,89	1,62
220	220 - 230	225	468,2	1,6	13,75	0,85	1,64
230	230 - 240	235	509,9	1,5	13,11	0,82	1,65
240	240 - 250	245	553,4	1,45	12,88	0,79	1,66
250	250 - 260	255	598,7		0,00		1,67

From the website of the Zemach Feed Mill Company Israel (accessed in 2014): *Tilapia growing and feeding Table*. Water temperature of 27 – 29 °C. The feeding level expressed in % feed intake were converted into grams per kg metabolic weight (per BW(g)<sup>0,80</sup>) with the formula: Feed intake per kg metabolic weight (per BW(kg)<sup>0,80</sup>) = 10 \* (% feed intake per day) / (BW(kg)<sup>-0,20</sup>).

**Table 9**  
 The Feeding Table of the SRAC for Tilapia (Publication 281)

Body weight (grams)	Feed Intake % of body weight	Feed Intake g/BW(kg) <sup>0,80</sup>
<0,5	15-20	
0,5	17,5	38,3
1	11	27,6
2	9	26,0
5	6,5	22,5
10	5,2	20,7
15	4,6	19,9
20	4,2	19,2
30	3,6	17,9
60	3	17,1
100	2,5	15,8
175	2,5	17,6
300	2,1	16,5
400	1,5	12,5

SRAC, South Regional Aquaculture Center, Cage Culture of Tilapia, Publication 281. A.S. McGinty and J.E. Racozy (can be downloaded from the internet) (accessed in 2014). No water temperature is given. The feeding level expressed in % feed intake were converted into grams per kg metabolic weight (per BW(g)<sup>0,80</sup>) with the formula: Feed intake per kg metabolic weight (per BW(kg)<sup>0,80</sup>) = 10 \* (% feed intake per day) / (BW(kg)<sup>-0,20</sup>).

**Table 10**  
 The Feeding Table of the NRC for Tilapia (1993)

Body Weight grams	Feed Intake % of body weight	Body Weight grams	Feed Intake %	Feed Intake g/BW(kg) <sup>0,80</sup>
2 days old - 1	30 - 10			
1 - 5	10 - 6	1	10	25,12
5 - 20	6 - 4	5	6	20,79
20 - 100	4 - 3	20	4	18,29
100 +	3	100	3	18,93

NRC at the Internet: [http://www.nap.edu/catalog.php?record\\_id=2115#toc](http://www.nap.edu/catalog.php?record_id=2115#toc) Accessed in 2014. Water temperature of 28 °C. The feeding level expressed in % feed intake were converted into grams per kg metabolic weight (per BW(g)<sup>0,80</sup>) with the formula: Feed intake per kg metabolic weight (per BW(kg)<sup>0,80</sup>) = 10 \* (% feed intake per day) / (BW(kg)<sup>-0,20</sup>).



We plotted the feeding levels (% of body weight) vs the body weights of the Tilapia of the various feeding tables (Figure 8). Linear plots should arise when the data were plotted on a double logarithmic scale. The slope and the intercept of these plots can be calculated with linear regression and allometric scaling equations can be constructed of the form:

$$\% \text{ feed intake} = a * \text{BW}(\text{kg})^b$$

where a is the normalization constant and b is the scaling coefficient and the body weights BW(kg) are expressed in kilograms.

For example, the feeding levels of Biomar (Table 7) expressed in % of body weight were plotted vs the body weights in kilograms for a temperature of 27 °C (Figure 8). The regression line describing this linear plot was calculated to be :

$$\log (\% \text{ feed intake}) = \text{intercept} + b * \log \text{BW}(\text{kg})$$

$$\log (\% \text{ feed intake}) = 0.1935 - 0.3556 * \log \text{BW}(\text{kg})$$

$$\text{anti-log of } 0.1935 = 1.5612$$

$$\log \% \text{ feed intake} = \log 1.5612 - 0.3556 * \log \text{BW}(\text{kg})$$

$$\log \% \text{ feed intake} = \log 1.5612 + \log (\text{BW}(\text{kg})^{-0.3556})$$

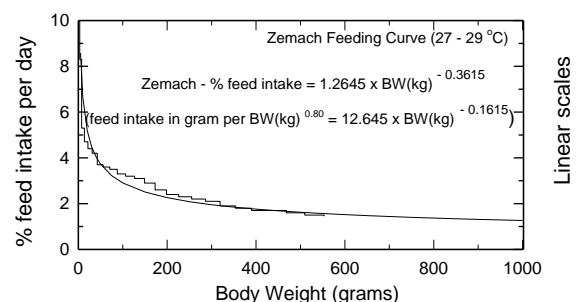
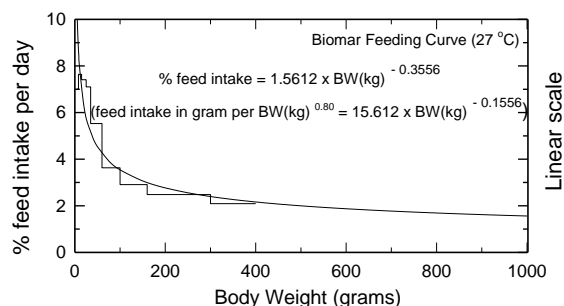
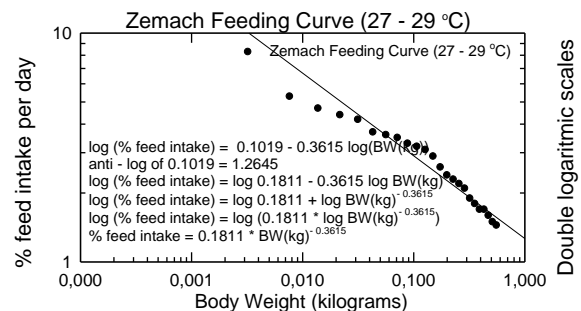
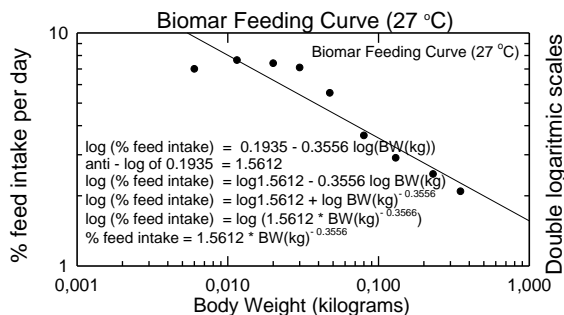
$$\log \% \text{ feed intake} = \log (1.5612 * \text{BW}(\text{kg})^{-0.3556})$$

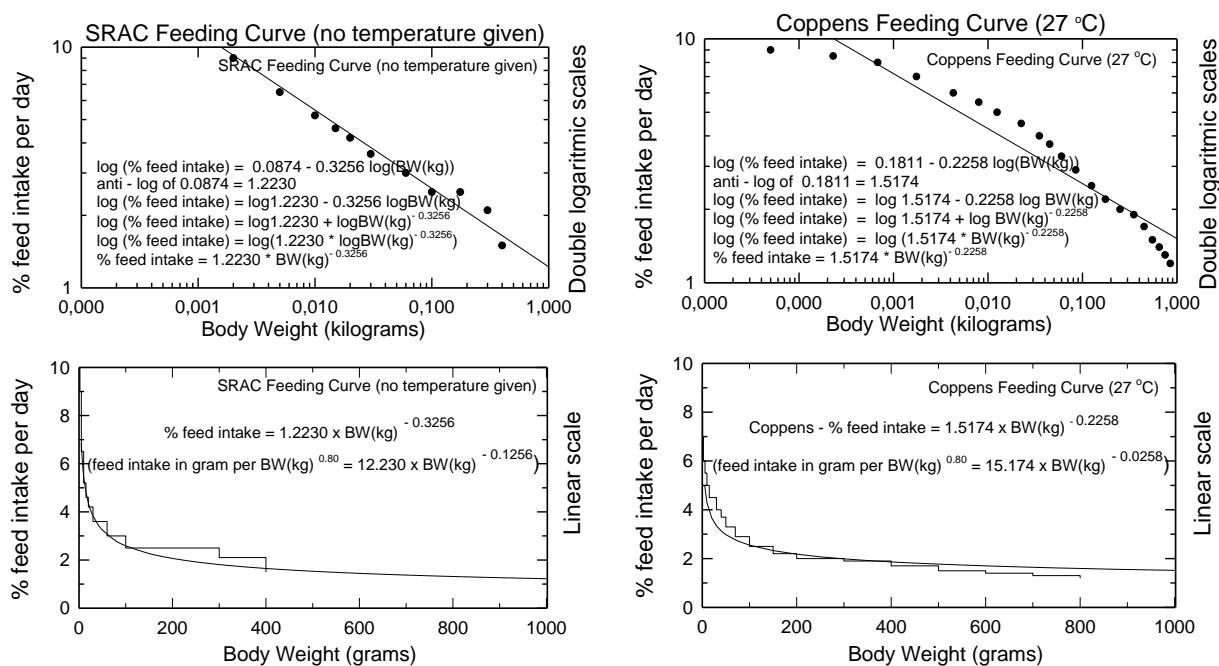
$$\% \text{ feed intake} = 1.5612 * \text{BW}(\text{kg})^{-0.3556}$$

(for the properties of logarithms, see paragraph 13 )

The various fitted feeding curves expressed as percentage of body weight are:

- Biomar:  $\% \text{ feed intake} = 1.5612 * \text{BW}(\text{kg})^{-0.3556}$  (27 °C)  
 Zemach:  $\% \text{ feed intake} = 1.2645 * \text{BW}(\text{kg})^{-0.3615}$  (27 - 29 °C)  
 SRAC:  $\% \text{ feed intake} = 1.2230 * \text{BW}(\text{kg})^{-0.3256}$  (no temperature given)  
 Coppens:  $\% \text{ feed intake} = 1.5174 * \text{BW}(\text{kg})^{-0.2258}$  (27 °C)





**Figure 8**

Feeding curves of Biomar (Table 7), Zemach (Table 8), SRAC (Table 9) and Coppens (Table 6)

The feed intake expressed in % of body weight can be converted into the feed intake per kg metabolic weight (per BW(kg)<sup>0.80</sup>) as following (formula 1, page 12):

$$\text{Feed Intake per kg metabolic weight} = c = 10 * (\% \text{ feed intake per day}) / (\text{BW(kg)})^{-0.20}$$

For example, the formula for the feed intake expressed as % of body weight of the feeding levels of Biomar at a temperature of 27 °C is:

$$\% \text{ feed intake} = 1.5612 * \text{BW(kg)}^{-0.3556} \text{ (27 °C)}$$

Substitution into the conversion formula gives:

$$\text{Feed Intake per kg metabolic weight} = c = 10 * (1.5612 * \text{BW(kg)}^{-0.3556}) / (\text{BW(kg)})^{-0.20} \text{ or}$$

$$\text{Feed Intake per kg metabolic weight} = c = 15.612 * \text{BW(kg)}^{-0.1556}$$

Similarly, the feed intakes expressed in grams per kg metabolic weight can be calculated for the other feeding curves:

- Biomar: feed intake (per BW(kg)<sup>0.80</sup>) = 15.612 \* BW(kg)<sup>(-0.1556)</sup> (27 °C)
- Zemach: feed intake (per BW(kg)<sup>0.80</sup>) = 12.645 \* BW(kg)<sup>(-0.1615)</sup> (27 – 29 °C)
- SRAC: feed intake (per BW(kg)<sup>0.80</sup>) = 12.230 \* BW(kg)<sup>(-0.1256)</sup> (no temperature given)
- Coppens: feed intake (per BW(kg)<sup>0.80</sup>) = 15.174 \* BW(kg)<sup>(-0.0258)</sup> (27 °C)

## 7 Construction of a General Feeding Curve for Tilapia

We can construct two different types of feeding curves:

(a) where the ratio of metabolizable energy for production / metabolizable energy for maintenance (Mp/Mm) is the same for all different sizes of Tilapia and independent of the body weights and the feed intake per kg metabolic weight (per BW(kg)<sup>0.80</sup>) is then also the same for all the various sizes of Tilapia and is also independent of the body weights. In this situation, the scaling coefficient of the feeding curve or formula describing the feed intake as percentage of body weight (% feed intake = a \* BW(kg)<sup>b</sup>) has to be b = - 0.2.

(b) where the ratio of metabolizable energy for production / metabolizable energy for maintenance ratio (Mp/Mm) is different for all different sizes of Tilapia and dependent of the body weights and thus relatively less energy is used for growth and relatively more for maintenance when the trout grows larger. The feed intake per kg metabolic weight (per BW(kg)<sup>0.80</sup>) is then also different for all the various sizes of trout and is dependent on the body weights. In this situation, the scaling coefficient of the feeding curve or formula describing the feed intake as percentage of body weight (% feed intake = a \* BW(kg)<sup>b</sup>) has to be different from - 0.20 (or b ≠ - 0.20).

Details for the construction of these two types of feeding curves are given in the article: "Feeding and growth parameters of trout", paragraph 6).

We will construct here a feeding curve for Tilapia where where the ratio of metabolizable energy for production / metabolizable energy for maintenance ratio (Mp/Mm) is different for all different sizes of Tilapia. We can construct a general feeding formula where the feed intake is expressed as % of body weight with a allometric scaling formula:

$$\% \text{ feed intake} = a * \text{BW(kg)}^b$$

where "a" is the normalization constant and "b" is the scaling coefficient. We can choose a value for "a" and "b" depending on the feeding levels we are interested in. Note that increasing or decreasing the normalization "a" constant will linearly increase or decrease the feeding level. The scaling coefficient, however, determines the slope of the feeding curve and a change of the scaling coefficient will affect how fast the feeding level will decrease when the Tilapia grows larger.

The scaling coefficient of the feeding curves of Zemach, Biomar and SRAC are - 0.3615, - 0.3556, and - 0.3256. Thus we could use a value of - 0.350 as the scaling factor for feeding curves for Tilapia and the feeding formula becomes then:

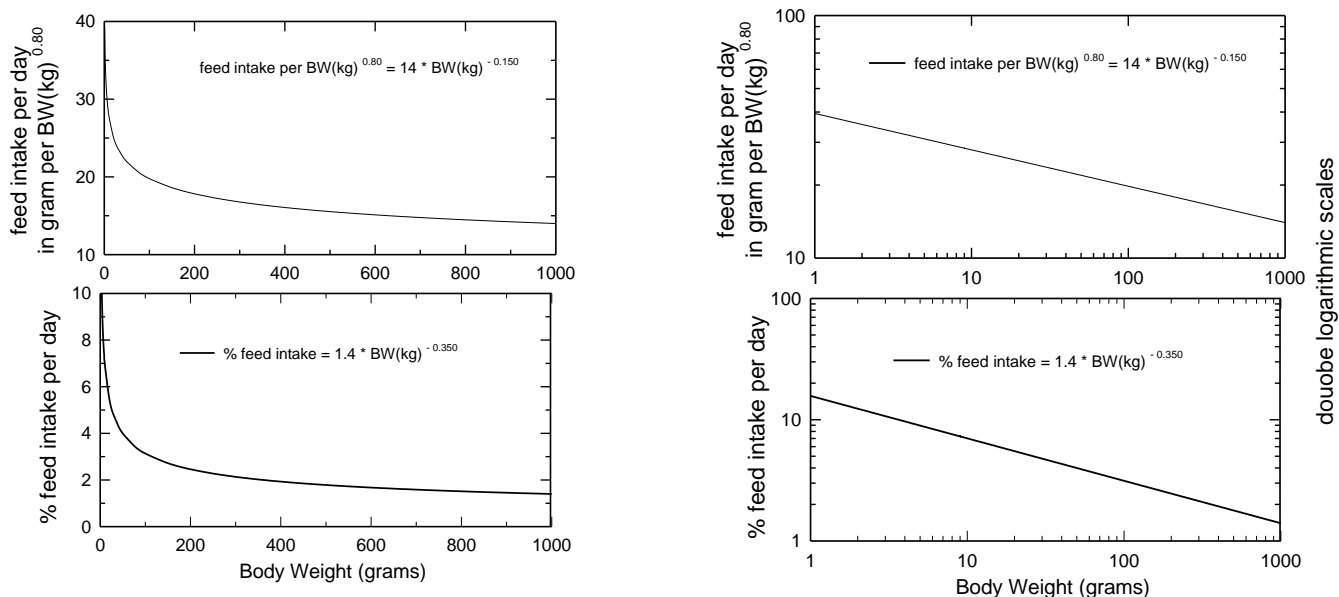
$$\% \text{ feed intake} = a * \text{BW(kg)}^{-0.350}$$

We could use a value of "a" = 1.40 for a general feeding curve for Tilapia. This value gives a feeding curve between that of Biomar and that of Zemach and the feeding curve becomes then;

$$\% \text{ feed intake} = 1.4 * \text{BW(kg)}^{-0.350}$$

and expressed in gram per kg metabolic weight (formula 1, page 12):

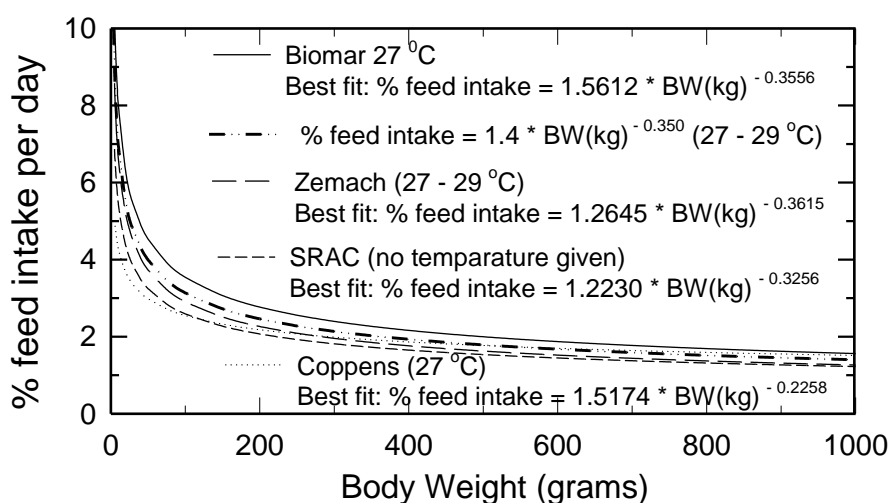
$$\text{feed intake in grams per BW(kg)}^{0.80} = 14 * \text{BW(kg)}^{-0.150}$$



**Figure 9**  
 General feeding curve for *Tilapia* at a water temperature of about 27 – 29 °C.

The feeding level expressed in % of body weight decreases when the body weight of the *Tilapia* increases. In addition, the feed intake as expressed in grams per kg metabolic weight (per  $BW(kg)^{0.80}$ ) also decreases when the body weight of the *Tilapia* increases; as a consequence, the the ratio of metabolizable energy for production / metabolizable energy for maintenance (Mp/Mm) also decreases when the body weight of the *Tilapia* increases (see article “*Feeding and growth parameters of trout*” for details, paragraph 6).

We can linearly decrease or increase the feeding level by decreasing or increasing the value for “a”, the normalization constant of the feeding formula. This way, various feeding levels and curves for *Tilapia* can be generated.



**Figure 10**  
 General feeding curve for *Tilapia* at a water temperature of about 18 – 20 °C compared with feeding curves as recommended by Biomar, Zemach, SRAC and Coppens.

**Example:** The feeding curve is:

$$(1) \% \text{ feed intake} = 1.4 * \text{BW}(\text{kg})^{-0.350} \text{ or}$$
$$(2) \text{ feed intake (per BW}(\text{kg})^{0.80}) = 14 * \text{BW}(\text{kg})^{(-0.150)}$$

We have for example a Tilapia of 150 grams:

$$(1) \% \text{ feed intake} = 1.4 * \text{BW}(\text{kg})^{-0.350} = 1.4 * 0.150^{(-0.350)} = 2.72$$

The feed intake is then  $0.0272 * 150 = 4.08$  grams of feed.

$$(2) \text{ feed intake (per BW}(\text{kg})^{0.80}) = 14 * \text{BW}(\text{kg})^{(-0.150)} = 14 * 0.150^{(-0.150)} = 18.61$$

The feed intake is then  $18.61 * \text{BW}(\text{kg})^{0.80} = 18.61 * 0.150^{0.80} = 4.08$  grams of feed.

## 8 Growth Curves for Tilapia

(for details, see the article: *Some aspects of energy metabolism in homeotherm animals and poikilotherm fish*)

Two major types of growth curves can be used for Tilapia, the exponential growth curve and the power growth curve, also called the Daily Growth Coefficient (DGC) growth curve (*Iwama, 1981, Kaufman, 1981*). The exponential growth curve can be used to describe the growth of Tilapia larvae, up to about 10 - 30 grams, and the power growth curve to describe the growth of larger size Tilapia.

**The exponential growth curve is described by the formula:**

$$\text{BW}_1 = \text{BW}_0 e^{\alpha t}$$

which is an exponential function where  $t$  is the time in days and  $\text{BW}_0$  is the body weight when  $t=0$ . The logarithmic and linear form is:

$$\ln(\text{BW}_1) = \ln(\text{BW}_0 * e^{\alpha t}) = \ln \text{BW}_0 + \alpha t \ln e = \ln \text{BW}_0 + \alpha t$$

A growth curve fits an exponential growth curve when a linear plot arises when the  $\ln$  values of the body weights are plotted vs the time. An example of the exponential growth curve is given in Figure 12. The  $\ln$  values of the body weights are plotted vs the time (days). The slope  $\alpha$  and the intercept ( $\ln \text{BW}_0$ ) of this linear plot can be calculated by linear regression and the slope  $\alpha$  is the exponent of the function and the anti- $\ln$  of the intercept ( $\ln \text{BW}_0$ ) is  $\text{BW}_0$  at  $t=0$ .

The slope  $\alpha$  can also be estimated by taking two points of the graph and using the formula (shortened method):

$$\alpha = \ln \text{BW}_{t=t2} - \ln \text{BW}_{t=t1}$$

When we have calculated the value of  $\alpha$  and  $\text{BW}_0$  (the anti- $\ln$  of the intercept), then we can calculate the body weights at each time point with the formula:  $\text{BW}_1 = \text{BW}_0 e^{\alpha t}$  for any value of  $\text{BW}_0$ .

**Example:** The growth of Tilapia larvae is for example described by the exponential function:

$$\text{BW}_1 = \text{BW}_0 * e^{\alpha t} = 0.0962 * e^{0.0654t} \text{ where } \text{BW}_0 \text{ is the BW at } t = 0 \text{ and is in this example } 0.0962 \text{ grams}$$

The body weight at  $t = 60$  days is:

$$\text{BW}_1 = 0.0962 * e^{0.0654*60} = 4.87 \text{ grams.}$$

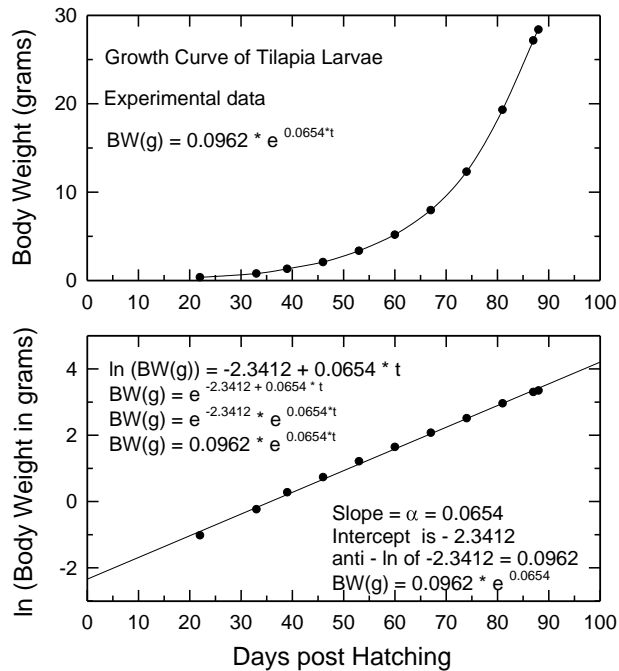
The body weight after another 10 days is:

**Method 1:**

$$BW_1 = BW_0 * e^{\alpha t} = 4.87 * e^{0.0654 * 10} = 9.37 \text{ grams}$$

**Method 2:**

$$BW_1 = BW_0 * e^{\alpha t} = 0.0962 * e^{0.0654 * 70} = 9.36 \text{ grams.}$$



**Figure 11**  
*Exponential growth curve of Tilapia larvae*

Further, we can calculate the time that is needed to double the body weights:

$$t = t_2 - t_1 = \frac{\ln 2}{\alpha}$$

Similarly, the time needed to triple the body weights is:

$$t = t_2 - t_1 = \frac{\ln 3}{\alpha}$$

**Example:** When  $\alpha = 0.0654$ , then the time to double the body weights is:  $\ln 2 / 0.0654 = 10.6$  days.  
Note that the time to double (or triple) the body weights is independent of the initial body weight.

Note that the time to double (or triple) the body weights is independent of the initial body weight.

In addition, we can calculate the % of growth per unit of time (see: *Some Aspects of Energy Metabolism in Homeotherm Animals and Poikilotherms Fish*)

$$\% \text{ growth per time unit of } t_1 - t_0 = 100\% * e^{\alpha(t_1 - t_0)} - 1$$

And the % growth per day is ( $t_1 - t_2 = 1$ ):

$$\% \text{ growth per day} = 100\% * (e^{\alpha} - 1)$$

Note that the % growth per day is independent of the (initial) body weight.

**Example:** Suppose that we calculated from experimental data that  $\alpha = 0.05$  and we want to calculate the % growth per day, thus  $t_1 - t_0 = 1$  day.

$$\begin{aligned}\% \text{ growth per day} &= 100\% * (e^{\alpha} - 1) \\ \% \text{ growth per day} &= 100\% * e^{0.05} - 1) = 5.127\% \text{ per day}\end{aligned}$$

This result means that the body weights will increase every day with 5.127%, independently of the (initial) body weights. A similar phenomenon is seen with an amount of money on the bank with a so called compound interest rate per year; every year the amount of money will increase with the percentage of the interest rate, independent of the (initial) amount of money on the bank.

The percentage growth per day is usually called the specific growth rate (SGR). In financial terms it is called the interest rate per year. Mostly, the value of  $\alpha$  is used as the SGR, but this is not really correct, although the differences between the value of  $\alpha$  and the SGR as calculated above is not much different (5.0 vs 5.12% in the example above). Similarly, we can calculate the % growth per 2 days, 3 days etc.

### **The power growth curve is described by the formula:**

$$BW^{1/3}_{\text{day}=1} = BW^{1/3}_{\text{day}=0} + c t$$

which is a linear function where  $BW^{1/3}$  is the body weight raised to the power 1/3,  $t$  is time (days),  $c$  is the slope of the graph, and  $BW^{1/3}_{\text{day}=0}$  is the body weight raised to the power 1/3 when  $t=0$ . The slope  $c$  multiplied by 100 is called the Daily Growth Coefficient (DGC, *Iwama 1981*). A growth curve fits a power growth curve when a linear graph arises when the values of the body weights raised to the power 1/3 are plotted vs the time. The slope  $c$  of this linear plot and the intercept  $BW^{1/3}_{\text{day}=0}$  can be calculated with linear regression. Also a power coefficient different from 1/3 has sometimes to be used to fit a power growth curve. The correct power coefficient can be found by trial and error. A correct power coefficient means that the body weights raised to the power coefficient and plotted vs the time results in a linear curve.

The formula can also be written as:

$$BW_{\text{day}=1} = (BW^{1/3}_{\text{day}=0} + c t)^3$$

and, since the daily growth coefficient (DGC) is  $c * 100$ :

$$BW_{\text{day}=1} = (BW^{1/3}_{\text{day}=0} + (DGC/100) t)^3$$

When we know the DGC, we can calculate with this formula the body weights  $BW_{\text{day}=1}$  at various time points for any value of  $BW_{\text{day}=0}$ .

### **How to calculate the the DGC:**

#### **Method 1.**

When a set of growth data are given (various time points with various body weights), then all the (body weights)<sup>d</sup> are plotted versus the time. Then, by means of a linear regression analysis, the intercept (intercept is BW<sup>d</sup> when time = 0) and the slope (x 100 = DGC) can be calculated. The value for d has to be determined by trial and error. A correct value for d has been found when the graph of the values of the (body weights)<sup>d</sup> vs the time is a linear graph. For Tilapia of about 20 – 700 grams a value for d of 0.333 appears to be suitable.

Method 2.

When only the body weights at two time points are known and one is confident that these two time points are the points of a linear curve describing the BW<sup>d</sup> vs time, then the slope can be calculated as follows:

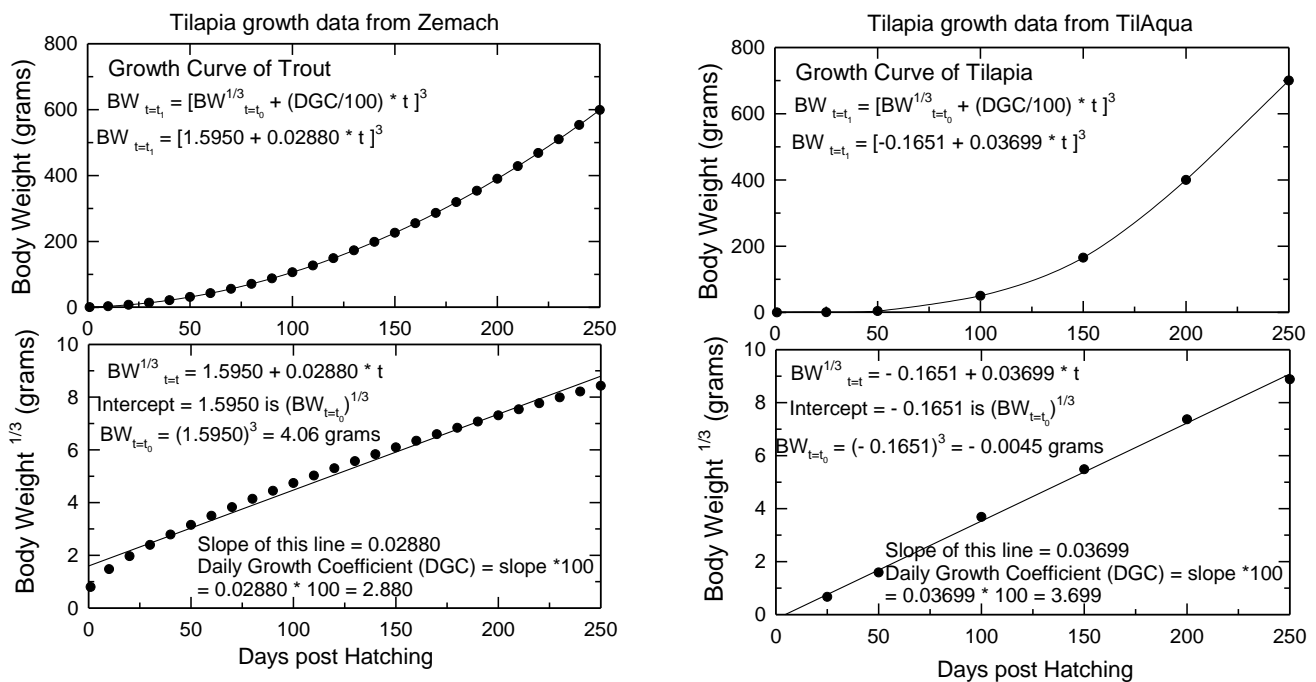
$$BW^d_{\text{day}=1} = BW^d_{\text{day}=0} + c \cdot \text{days}$$

$$c = (BW^d_{\text{day}=1} - BW^d_{\text{day}=0}) / \text{days}$$

This c is per definition the slope of the graph (c). The DGC is then c\*100. The DGC is expressed as % (weight gain)<sup>d</sup> per day.

$$\text{Daily Growth Coefficient} = \text{DGC} = 100\% \cdot (BW^d_{\text{day}=1} - BW^d_{\text{day}=0}) / \text{days}$$

Figure 12 shows a power growth curve of Tilapia. The best fit value of d (the exponent of the body weight) was 1/3 = 0.33. This value was found by trial and error, i.e. a linear graph is generated when the body weights raised to this power are plotted vs the time (see bottom panels of Figure 12).



**Figure 12**

Power growth curves of Tilapia. The data of TilAqua were kindly provided by TilAqua (website: [www.TilAqua.nl](http://www.TilAqua.nl)) and the Data from Zemach were retrieved from the internet ([www.Zemach.com](http://www.Zemach.com)).

The calculated DGC can be used to predict body weights after a defined number of days as:



$$\text{Final Body Weight} = [ (\text{Initial Body Weight})^{1/3} + (\text{DGC}/100) * \text{days on diet} ]^3$$

Further, when the final body weight is known, the number of days, and the DGC, then the initial body weight can be calculated:

$$\text{Initial Body Weight} = [ (\text{Final Body Weight})^{1/3} - (\text{DGC}/100) * (\text{days on diet}) ]^3$$

Similarly, when the initial body weight is known and the DGC, then it can be calculated after how many days a defined body weight has been reached:

$$\text{Days on Diet} = 100 * [ (\text{Final Body Weight})^{1/3} - (\text{Initial Body Weight})^{1/3} ] / (\text{DGC})$$

**Example:** The body weight at day 100 is 50 grams and the body weight at day 200 is 400 grams and  $d = 1/3$ , thus number of days is 100 days (data TilAqua), then the DGC is:

$$\begin{aligned} \text{DGC} &= 100\% * (\text{BW}_{\text{day=1}}^{1/3} - \text{BW}_{\text{day=0}}^{1/3}) / \text{days} \\ \text{DGC} &= 100 * [(400)^{1/3} - (50)^{1/3}] / 100 = 3.68 \% \text{ (weight gain)}^{1/3} \text{ per day} \\ &\text{(compare with the value of 3.70 in Figure 14)} \end{aligned}$$

**Example:** The initial body weight is 50 grams and  $d = 1/3$  and the DGC is 3.68. Then the body weight after 100 days can be calculated as

$$\begin{aligned} \text{Final Body Weight} &= [ (\text{Initial Body Weight})^{1/3} + (\text{DGC}/100) * \text{days on diet} ]^3 \\ \text{Final Body Weight} &= [ (50)^{1/3} + (3.68 / 100) * 100 ]^3 = 400 \text{ grams.} \end{aligned}$$

**Example:** The final body weight is 400 grams at 200 days and the DGC is 3.68. Then the body weight at 150 days is (thus days on diet is  $200 - 150 = 50$  days):

$$\begin{aligned} \text{Initial Body Weight} &= [ (\text{Final Body Weight})^{1/3} - (\text{DGC}/100) * (\text{days on diet}) ]^3 \\ \text{Initial Body Weight at day 150} &= [ (400)^{1/3} - (3.68/100) * (50) ]^3 = 169 \text{ grams} \end{aligned}$$

**Example:** The initial body weight is 50 grams and  $d = 1/3$  and the DGC is 3.68. How long does it take to double the body weight?

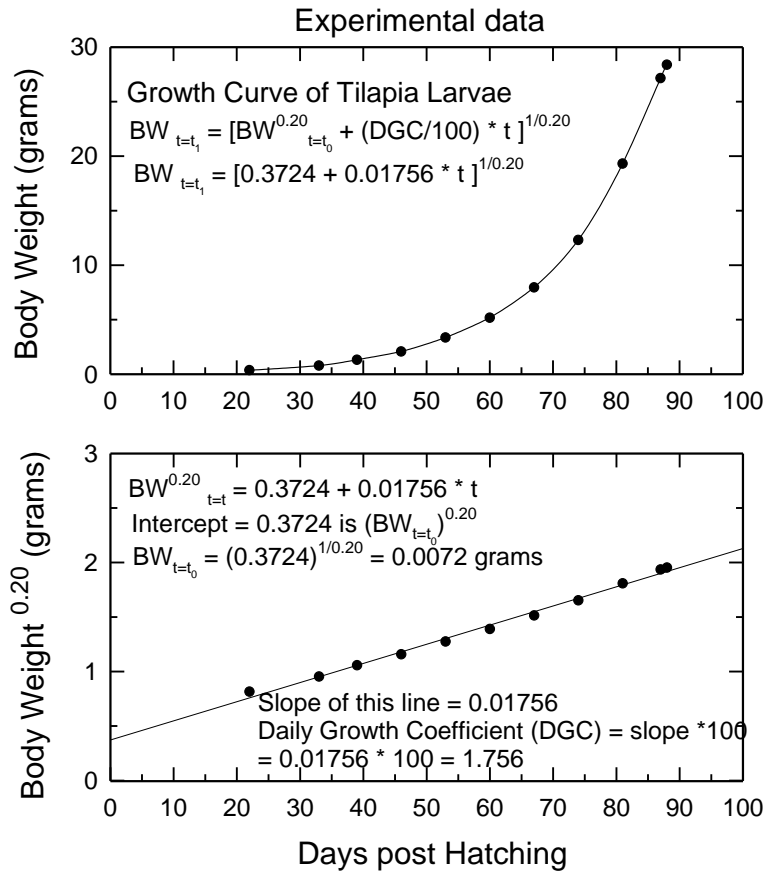
$$\begin{aligned} \text{Days on Diet} &= 100 * [ (\text{Final Body Weight})^{1/3} - (\text{Initial Body Weight})^{1/3} ] / (\text{DGC}) \\ \text{Days on Diet} &= 100 * [ (100)^{1/3} - (50)^{1/3} ] / (3.68) = 26 \text{ days} \end{aligned}$$

Note that the time to double the body weight is dependent on the initial body weight (see example below). The time to double the body weight for an exponential growth curve is independent of the initial body weight.

**Example:** The initial body weight is 100 grams and  $d = 1/3$  and the DGC is 3.68. How long does it take to double the body weight?

$$\begin{aligned} \text{Days on Diet} &= 100 * [ (\text{Final Body Weight})^d - (\text{Initial Body Weight})^d ] / (\text{DGC}) \\ \text{Days on Diet} &= 100 * [ (200)^{1/3} - (100)^{1/3} ] / (3.68) = 32.8 \text{ days} \end{aligned}$$

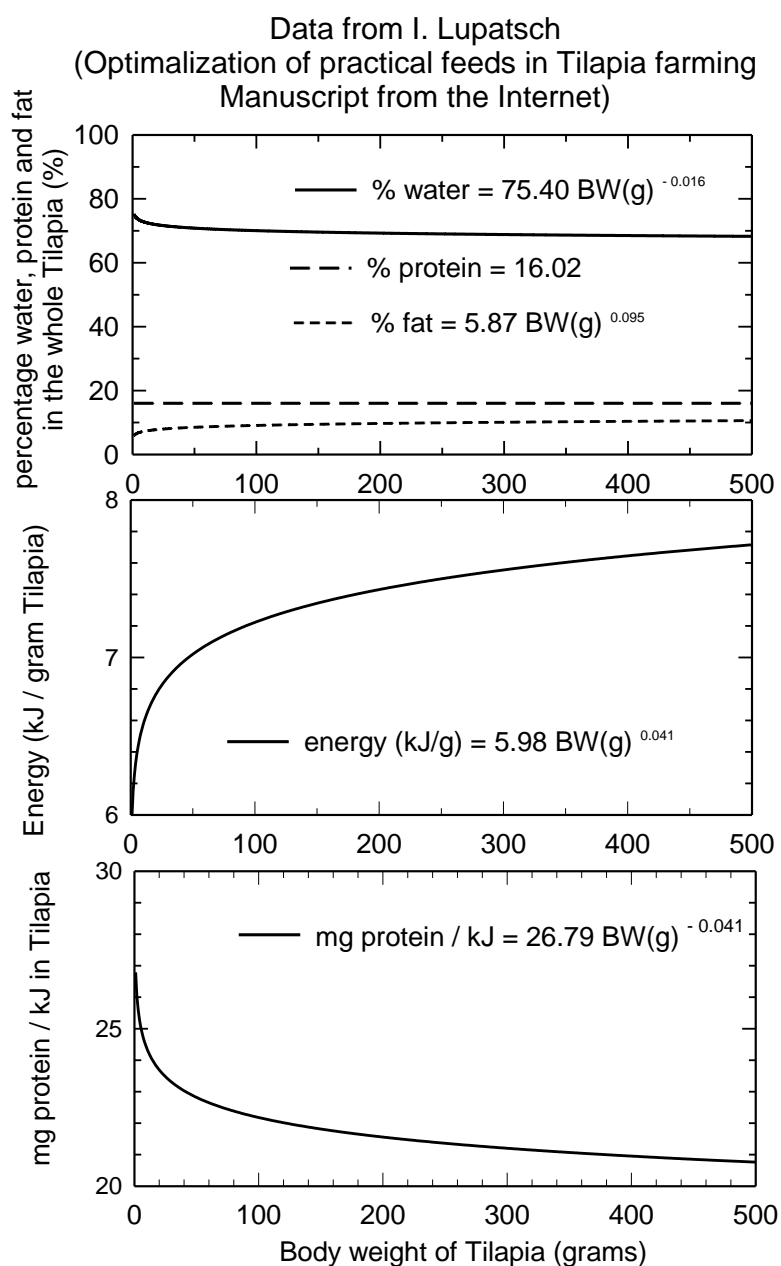
The exponential growth curve is mostly used to describe the growth of Tilapia larvae up to about 10 - 30 grams whereas the power growth curve is used for larger size Tilapia. However, the power growth curve can also be used to describe the growth rate of Tilapia larvae, but a power coefficient smaller than  $1/3 = 0.333$  has to be used. The correct power coefficient has to be found by trial and error and we found that a power curve with a power coefficient of 0.20 can also describe the growth rate of Tilapia larvae instead of an exponential growth curve. Dumas et al. (2007b) described that various power coefficients may be used dependent on the size of fish and the growth stanza. Figure 13 shows that the growth curve of Tilapia larvae can also be described by a power growth curve instead of an exponential growth curve.



**Figure 13**  
 Power growth curve of Tilapia larvae

## 9 Body Composition of the Tilapia

The major components of the Tilapia are water, protein, fat and ash. The proportion of protein in the body is rather constant (about 15 - 20%) and the same is true for the ash content (about 2%). However, the fat and water content can vary strongly and is dependent on various factors such as e.g. the feeding level and the composition of the diets. Further, the fat and the water content are negatively correlated with each other, i.e. a high fat content is associated with a low water content. When the correlation between water content and fat content is known, then the proportion of fat in the body can be derived from the water content in the body. The water content of the body of experimental animals can be easily measured by drying in an oven.



**Figure 14**  
 Body composition of Tilapia

The amount of protein, fat, water and ash in the body can be described by the allometric scaling equation:

$$\text{amount (\%)} = a \cdot \text{BW(g)}^b$$

where  $a$  is the normalization constant,  $\text{BW}$  is the body weight in grams and  $b$  is the scaling coefficient. Ingrid Lupatsch (2008) has described the body composition of Tilapia (Optimization of practical feeds in Tilapia farming. Manuscript retrieved from the Internet in 2010).

The formulae for the percentages and total amounts of protein, fat, ash and water are:

$$\text{Moisture (\%)} = 75.40 \text{ BW(g)}^{-0.016}$$

$$\text{Fat (\%)} = 5.87 \text{ BW(g)}^{0.095}$$

$$\text{Protein (\%)} = 16.02$$

$$\text{Ash (\%)} = 4.28$$

$$\text{Energy (kJ/g)} = 5.98 \text{ BW(g)}^{0.041}$$

$$\text{Moisture (g)} = 0.754 \text{ BW(g)}^{0.984}$$

$$\text{Fat (g)} = 0.0587 \text{ BW(g)}^{1.095}$$

$$\text{Protein (g)} = 0.1602 \text{ BW (g)}$$

$$\text{Ash (g)} = 0.0428 \text{ BW (g)}$$

$$\text{Energy (kJ)} = 5.98 \text{ BW(g)}^{1.041}$$

$$\text{mg protein / kJ} = 26.79 \text{ BW(g)}^{-0.041}$$

The data derived from Tilapia in the weight range of about 0 – 450 grams and the mg protein / kJ were calculated from the body energy and the body protein data.

## 10 Factors that affect the Performance of a Tilapia Feed: the 4 P's concept.

Protein drives the growth and the maximum growth of a trout is determined by the maximum capacity to deposit protein. Thus, it is important that sufficient protein (and protein with the right amino acid composition) can be taken up to achieve this maximum protein deposition and growth. On the other hand, the intake of excess of protein that exceeds the maximum capacity to deposit the protein, and also excess of energy will result in the deposition of fat and result in fatty fish. Thus, the right ratio of energy to protein and the right amount of feed is important for optimal growth. As a rule of thumb, the ratio mg digestible protein / kJ digestible energy in growing fish should be similar to this ratio of the fish itself see also: feeding manual for trout, paragraph on phase feeding).

A factor that determines the uptake of a feed is the palatability of the feed. A feed that is not attractive to the Tilapia will result in a low feed intake and thus in a low protein intake. A high feed intake results also in less energy for maintenance during the whole life span of the trout.

Further, the performance of a feed or the feed conversion ratio (FCR) is important. Factors that affect the performance are for example the digestibility of the protein, fat and carbohydrates in the diet and the amino composition of the protein.

An important issue in aquaculture is also the pollution. The feeds should have a high digestibility and generate little feces and the waste generated should not be loose but more compact in order to be able to collect easily the feces.

A final issue is the price of a Tilapia feed. The price should be right and the feeds should be cost effective.

Thus, the criteria for a good Tilapia feed (or a good trout feed ingredient) can be summarized with the 4 P's concept:

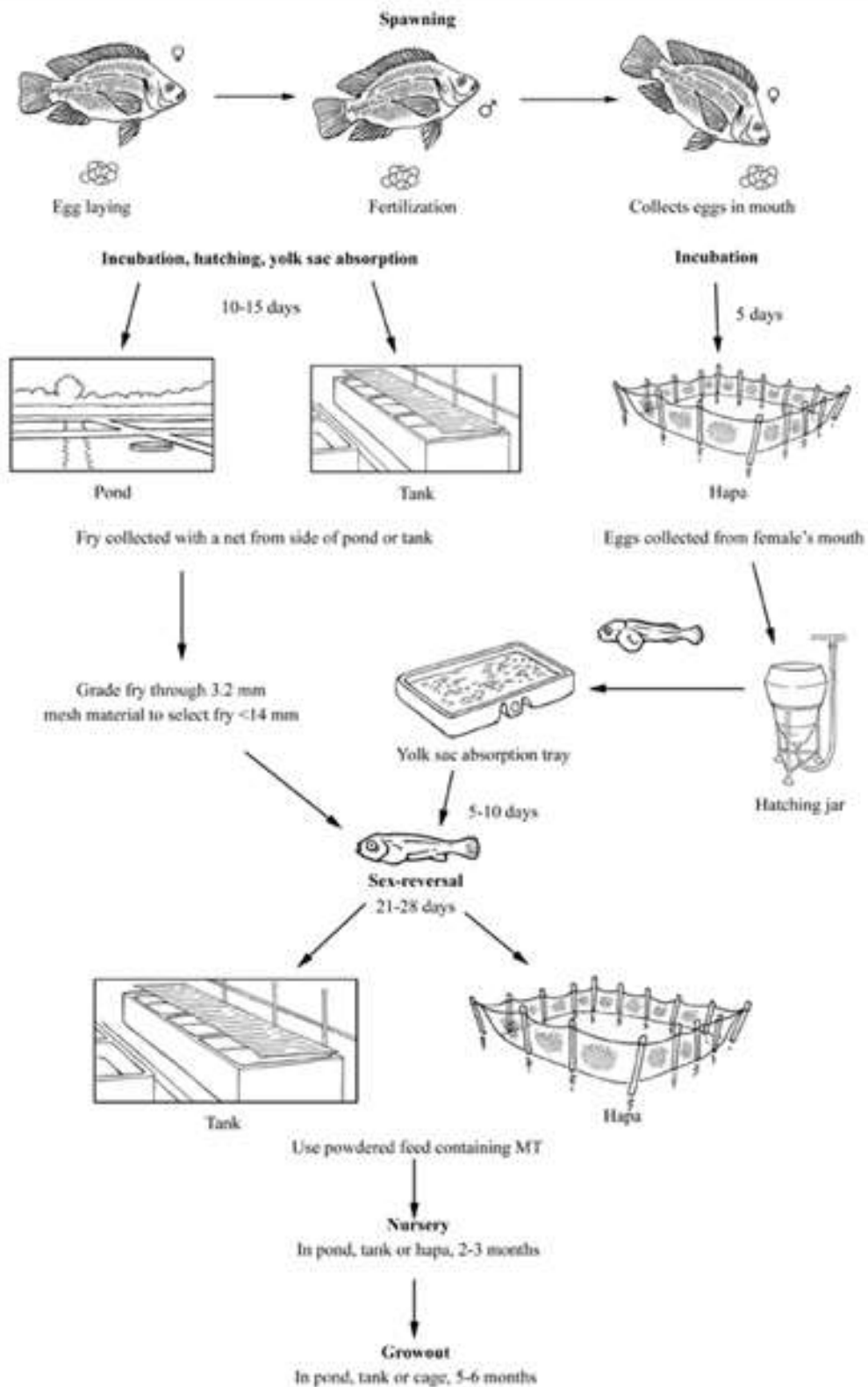
- |    |                      |   |
|----|----------------------|---|
| 5. | <b>P</b> alatability | Attractive feed to assure a high feed intake.                             |
| 6. | <b>P</b> erformance  | The FCR ratio should be as low as possible.                               |
| 7. | <b>P</b> ollution    | High digestibility and feces that are compact and thus easily to collect. |
| 8. | <b>P</b> rice        | The price should be right and the feed should be cost effective.          |

## 11 Literature

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- Iwama, G.K. & Tautz, F.A. (1981) A simple growth model for salmonids in hatcheries. *Can. J. Fish. Aquat. Sci* 38: 649-656.
- Kaufmann, K.W. (1981) Fitting and using growth curves. *Oecologia (Berl)* 49: 293-299.
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- Nutrient Requirements of cold water Fishes (1981). National Academy Press, Washington, D.C. ISBN 0-309-03187-7 (out of press).
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- Nutrient Requirements of Fish and Shrimp (2011). National Academy Press, Washington, D.C.
- Standard methods for the nutrition and feeding of farmed fish and shrimp by Albert G.J. Tacon. Volume 1 (the essential nutrients), volume 2 (Nutrient sources and composition), and volume 3 (Feeding methods)  
(Volume 1: <http://www.fao.org/docrep/field/003/AB470E/AB470E00.htm>)  
(Volume 2: <http://www.fao.org/docrep/field/003/AB468E/AB468E00.htm>)  
(Volume 3: <http://www.fao.org/docrep/field/003/AB467E/AB467E00.htm>)
- United States-Canadian Tables of Feed Composition, Nutritional data for United States and Canadian feed, Third revision(1982). National Academy Press, Washington D.C. ISBN 0-309-56850-1: <http://www.nap.edu/openbook/0309032458/html/index.html>
- INRA Feed Composition Tables. <http://www.trc.zootechnie.fr/node>
- USDA Food Tables on the Internet: (<http://www.nal.usda.gov/fnic/foodcomp/search/>) Gives the composition of food and food stuffs.
- DTU Food Tables on the Internet (Danish Technical University):  
[http://www.foodcomp.dk/v7/fcdb\\_default.asp](http://www.foodcomp.dk/v7/fcdb_default.asp)
- FAO website: Food Composition Tables for International Use (1955):  
<http://www.fao.org/docrep/x5557e/x5557e00.htm#Contents>

## 12. Production cycle of the Tilapia

### Production cycle



From The FAO Website: [http://www.fao.org/fishery/culturedspecies/Oreochromis\\_niloticus/en](http://www.fao.org/fishery/culturedspecies/Oreochromis_niloticus/en)

### 13. Energy values of fats, carbohydrates and proteins

The values for energy generated in the body, Respiratory Quotient (RQ) and the Energy Equivalents EeqO<sub>2</sub> and EeqCO<sub>2</sub> for carbohydrate, fat, protein and alcohol according to data from Elia and Livesey (1992).

	MW	Energy Generated in the Body <sup>1</sup>		H <sub>2</sub> O generated		O <sub>2</sub> consumed			CO <sub>2</sub> generated			RQ (CO <sub>2</sub> /O <sub>2</sub> )	EeqO <sub>2</sub> <sup>4</sup>		EeqCO <sub>2</sub> <sup>4</sup>		Atwater Digest.Coeffic (%)	Metabol Energy (kJ/g)	
		(kJ/mol)	(kJ/g)	(mol/mol)	(g/g)	(mol/mol)	(g/g)	(L/g)	(mol/mol)	(g/g)	(L/g)		(kJ/g)	(kJ/L)	(kJ/g)	(kJ/L)			
Protein (combustion) <sup>2</sup>	2260,0	53448	23,65	79,50	0,63	125,2	1,77	1,24	100,0	1,95	0,99	0,799	13,35	19,06	12,14	23,85	92	21,76	
Protein (in body) <sup>3</sup>	2260,0	45376	20,08	50,60	0,40	104,0	1,47	1,03	86,6	1,69	0,86	0,833	13,64	19,47	11,91	23,38	92	18,47	
Fat (dioleypalmitate) <sup>3</sup>	859,4	34022	39,59	51,00	1,07	77,5	2,89	2,02	55,0	2,82	1,43	0,710	13,72	19,59	14,06	27,61	95	37,61	
Carbohydrate (glucan) <sup>3</sup>	162,1	2840	17,52	5,00	0,56	6,0	1,18	0,83	6,0	1,63	0,83	1,000	14,79	21,12	10,76	21,12	97	16,99	
Sacharose (C <sub>12</sub> H <sub>22</sub> O <sub>11</sub> )	342,3	5641	16,48	11,00	0,58	12,0	1,12	0,79	12,0	1,54	0,79	1,000	14,69	20,98	10,68	20,98	97	15,99	
Glucose (C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> )	180,2	2803	15,56	6,00	0,60	6,0	1,07	0,75	6,0	1,47	0,75	1,000	14,60	20,85	10,62	20,85	97	15,09	
Alcohol (C <sub>2</sub> H <sub>6</sub> O)	46,1	1367	29,67	3,00	1,17	3,0	2,08	1,46	2,0	1,91	0,97	0,667	14,24	20,34	15,53	30,50	97	28,78	
<b><u>Kleibers standard protein</u></b>																			
<b><u>Data from Elia and Livesey<sup>5</sup></u></b>																			
Protein to mixture <sup>3</sup>	2260,0	45376	20,08	50,60	0,40	104,0	1,47	1,03	86,6	1,69	0,86	0,833	13,64	19,47	11,91	23,38	92	18,47	
Protein to urea	2260,0	45950	20,33	52,80	0,42	105,3	1,49	1,04	87,0	1,69	0,86	0,826	13,64	19,47	12,00	23,57	92	18,71	
Protein to uric acid	2260,0	41880	18,53	65,00	0,52	95,5	1,35	0,95	67,5	1,31	0,67	0,707	13,71	19,57	14,10	27,69	92	17,05	
Protein to ammonia	2260,0	46450	20,55	13,80	0,11	105,3	1,49	1,04	100,0	1,95	0,99	0,950	13,79	19,69	10,55	20,73	92	18,91	
Protein to creatinine	2260,0	33960	15,03	48,47	0,39	79,3	1,12	0,79	65,3	1,27	0,65	0,824	13,38	19,11	11,81	23,20	92	13,82	
Protein to allantoin	2260,0	43254	19,14	59,30	0,47	98,8	1,40	0,98	74,0	1,44	0,73	0,749	13,68	19,54	13,28	26,09	92	17,61	
<b><u>Kleibers standard protein</u></b>																			
<b><u>Calculated<sup>6</sup></u></b>																			
Protein to mixture <sup>3</sup>	2260,0	44415	19,68	50,60	0,40	104,0	1,47	1,03	86,6	1,69	0,86	0,833	13,35	19,06	11,65	22,89	92	18,08	
Protein to urea	2260,0	45037	19,93	52,80	0,42	105,3	1,49	1,04	87,0	1,69	0,86	0,826	13,37	19,09	11,76	23,10	92	18,33	
Protein to uric acid	2260,0	40962	18,12	65,00	0,52	95,5	1,35	0,95	67,5	1,31	0,67	0,707	13,40	19,14	13,79	27,08	92	16,67	
Protein to ammonia	2260,0	44270	19,59	13,80	0,11	105,3	1,49	1,04	100,0	1,95	0,99	0,950	13,14	18,76	10,06	19,76	92	18,02	
Protein to creatinine	2260,0	33193	14,69	48,47	0,39	79,3	1,12	0,79	65,3	1,27	0,65	0,824	13,08	18,68	11,54	22,67	92	13,51	
Protein to allantoin	2260,0			59,30		98,8			74,0										

**Data are from:**

M. Elia and G. Livesey (1992) Energy expenditure and fuel selection in biological systems: the theory and practice of calculations based on indirect calorimetry and tracer methods, World Review of Nutrition and Dietetics, volume 70, page 68-131 (see pages 71 and 78 for the equations of the oxidations of the carbohydrates, fats and proteins).

1. The energy generated is the energy generated in the body. For the protein, a correction is made for the energy excreted in the urine in the form of urea, ammonia, uric acid, creatine, creatinine, and allantoin. The protein in this Table refers to the Kleiber's standard protein (C<sub>100</sub> H<sub>159</sub> N<sub>26</sub> O<sub>32</sub> S<sub>0,7</sub> (MW = 2260, contains 16.1% N). The energy generated from the carbohydrates and the fat and alcohol in the body is identical to the energy generated in a bomb calorimeter.

2. Complete combustion of the Kleiber's protein in a bomb calorimeter. The heat of complete combustion of protein in the bomb calorimeter is 23.65 kJ/g (gross energy). The equation of the complete combustion is: C<sub>100</sub> H<sub>159</sub> N<sub>26</sub> O<sub>32</sub> S<sub>0,7</sub> + 124.8 O<sub>2</sub> = 100 CO<sub>2</sub> + 78.8 H<sub>2</sub>O + 13 N<sub>2</sub> + 0.7 H<sub>2</sub>SO<sub>4</sub> + 53448 kJ.

3. The Kleibers standard protein is metabolized to urea, creatinine and ammonia in the nitrogen mass ratio of 90:5:5 (See Elia and Livesey 1992, page 71):



$C_{100}H_{159}N_{26}O_{32}S_{0.7} + 104 O_2 (= 22.414 \times 104 = 2331.06 \text{ liters}) = 86.6 CO_2 (= 22.414 \times 86.6 = 1941.05 \text{ liters}) + 50.6 H_2O + 11.7 N_2H_4CO \text{ (urea)} + 1.3 NH_4OH \text{ (ammonia)} + 0.43 N_3C_4H_7O \text{ (creatinine)} + 0.7 H_2SO_4$

For the heat of combustion released from the oxidation of fat and carbohydrates, see Elia and Livesey 1992, page 71 and for the oxidation of saccharose and glucose and alcohol (ethanol): K. Blaxter 1989, page 296. (K. Blaxter (1989) Energy metabolism in animals and man, Cambridge University press).

4. Eeq, energy equivalent. All values for the volumes of  $O_2$  and  $CO_2$  are at 1 bar and a temperature of  $0^\circ C$  ( $273.15^\circ K$ ).  
 $1 \text{ mg } O_2 = 0.700 \text{ ml } O_2$  and  $1 \text{ ml } O_2 = 1.428 \text{ mg } O_2$ . Further  $1 \text{ mg } CO_2 = 0.509 \text{ ml } CO_2$  and  $1 \text{ ml } CO_2 = 1.963 \text{ mg } CO_2$

Data on energy equivalents of oxygen consumption for protein, fat and carbohydrates have also been given in earlier literature, see: J.M. Elliot and W. Davison (1975) Energy equivalents of oxygen consumption in animal energetics. Oecologia (Berlin) Volume 19, pages 195-201.

5. Data are from Elia and Livesey 1992 (page 71 and 78).

6. These data are calculated as following: The N in the protein can be excreted in the form of ammonia, urea, creatinine, creatin, or allantoin. These compounds contain a considerable amount of energy (See Appendix Table 4 and 5).

(a). Excretion of the nitrogen in the form of urea: the energy density of urea (in solution) is 647 kJ per mol ( $647 / 60.056 = 10.77$  kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 13 mol urea (Elia and Livesey 1992, page 78). This amount of urea contains thus  $13 \times 647 = 8411$  kJ of energy, which is excreted in the urine. The gross energy of protein is  $23.65 \times 2260 = 53448$  kJ. Thus  $53448 - 8411 = 45037$  kJ is left. Thus, the available energy of the protein is then  $45037 / 2260 = 19.93$  kJ per gram protein.

Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein):  $C_{100}H_{159}N_{26}O_{32}S_{0.7} + 105.3 O_2 = 87 CO_2 + 52.8 H_2O + 13 N_2H_4CO \text{ (urea)} + 0.7 H_2SO_4$

The complete combustion of Kleiber's protein is

(1)  $C_{100}H_{159}N_{26}O_{32}S_{0.7} + 124.8 O_2 = 100 CO_2 + 78.8 H_2O + 13 N_2 + 0.7 H_2SO_4 + 53448 \text{ kJ}$  and (complete combustion of protein)

(2)  $13 N_2H_4CO \text{ (urea)} + 19.5 O_2 = 13 CO_2 + 26 H_2O + 13 N_2 + 13 \times 647 \text{ kJ} (= 8411 \text{ kJ})$  (complete combustion of urea)

Subtract (2) from (1): (compare McLean and Tobin 1987, page 33, and Blaxter 1989, page 12, law of Hess, law of constant heat summation).

$C_{100}H_{159}N_{26}O_{32}S_{0.7} + 105.3 O_2 = 87 CO_2 + 52.8 H_2O + 13 N_2H_4CO \text{ (urea)} + 0.7 H_2SO_4 + 45037 \text{ kJ}$  or  $45037 / 2260 = 19.93$ .

We can also assume that protein in general contains 16% nitrogen (The Kleiber's protein contains 16.1% protein). Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Urea contains 46.6% nitrogen, thus the oxidation of 1 gram of protein results in the formation of  $0.16 / 0.46 = 0.34$  grams of urea. The energy density of 1 gram of urea is 10.77 kJ, thus the energy of 0.34 grams of urea is  $0.34 \times 10.77 = 3.66$  kJ and the available energy in 1 gram protein is then  $23.65 - 3.66 = 19.99$  kJ.

(b) Excretion of the nitrogen in the form of uric acid: the energy density of uric acid is 1921 kJ per mol ( $1921 / 168.112 = 11.42$  kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 6.5 mol uric acid (Elia and Livesey 1992, page 78). This amount of uric acid contains thus  $6.5 \times 1921 = 12487$  kJ of energy, which is excreted in the urine. The gross energy of protein is  $23.65 \times 2260 = 53448$  kJ. Thus  $53448 - 12487 = 40961$  kJ is left. Thus, the available energy of the protein is then  $40961 / 2260 = 18.12$  kJ per gram protein.

Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein):  $C_{100}H_{159}N_{26}O_{32}S_{0.7} + 95.5 O_2 = 67.5 CO_2 + 65 H_2O + 6.5 C_5H_4O_3N_4 \text{ (uric acid)} + 0.7 H_2SO_4$

We can also assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Uric contains 33.3% nitrogen, thus the oxidation of 1 gram of protein results in the formation of  $0.16 / 0.33 = 0.48$  grams of urea. The energy density of 1 gram of uric is 11.40 kJ, thus the energy of 0.48 grams of uric acid is  $0.48 \times 11.40 = 5.47$  kJ and the available energy in 1 gram protein is then  $23.65 - 5.47 = 18.18$  kJ.

(c) Excretion of the nitrogen in the form of ammonia: the energy density of ammonia (in solution) is 353 kJ per mol ( $353 / 17.031 = 20.73$  kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 26 mol ammonia (Elia and Livesey 1992, page 78). This amount of ammonia contains thus  $26 \times 353 = 9178$  kJ of energy, which is excreted in the urine. The gross energy of protein is  $23.65 \times 2260 = 53448$  kJ. Thus  $53448 - 9178 = 44270$  kJ is left. Thus, the available energy of the protein is then  $44270 / 2260 = 19.59$  kJ per gram protein.

Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein):  $C_{100}H_{159}N_{26}O_{32}S_{0.7} + 105.3 O_2 = 100 CO_2 + 13.8 H_2O + 26 NH_4OH$  (ammonia) +  $0.7 H_2SO_4$

We can also assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. ammonia contains 82.2% nitrogen, thus the oxidation of 1 gram of protein results in the formation of  $0.16 / 0.822 = 0.195$  grams of ammonia. The energy density of 1 gram of ammonia is 20.73 kJ, thus the energy of 0.13 grams of ammonia is  $0.195 \times 20.73 = 4.04$  kJ and the available energy in 1 gram protein is then  $23.65 - 4.04 = 19.61$  kJ.

(d) Excretion of the nitrogen in the form of creatinine: the energy density of creatinine is 2337 kJ per mol ( $2337 / 113.120 = 20.66$  kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 8.667 mol creatinine (Elia and Livesey 1992, page 78). This amount of creatinine contains thus  $8.667 \times 2337 = 20255$  kJ of energy, which is excreted in the urine. The gross energy of protein is  $23.65 \times 2260 = 53448$  kJ. Thus  $53448 - 20255 = 33193$  kJ is left. Thus, the available energy of the protein is then  $33193 / 2260 = 14.69$  kJ per gram protein.

Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein):  $C_{100}H_{159}N_{26}O_{32}S_{0.7} + 79.3 O_2 = 65.332 CO_2 + 48.466 H_2O + 8.667 N_3C_4H_7O$  (creatinine) +  $0.7 H_2SO_4$

We can also assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. creatinine contains 37.147% nitrogen, thus the oxidation of 1 gram of protein results in the formation of  $0.16 / 0.371 = 0.43$  grams of creatinine. The energy density of 1 gram of creatinine is 20.66 kJ, thus the energy of 0.43 grams of creatinine is  $0.43 \times 20.66 = 8.88$  kJ and the available energy in 1 gram protein is then  $23.65 - 8.88 = 14.77$  kJ.

(e) Excretion of the nitrogen in the form of creatine: the energy density of creatine is 2324 kJ per mol ( $2324 / 115.136 = 20.18$  kJ per gram). The oxidation of 1 mol of Kleiber's protein results in the formation of 8.667 mol creatine (Elia and Livesey 1992, own calculation). This amount of creatine contains thus  $8.667 \times 2324 = 20142$  kJ of energy, which is excreted in the urine. The gross energy of protein is  $23.65 \times 2260 = 53448$  kJ. Thus  $53448 - 20142 = 33306$  kJ is left. Thus, the available energy of the protein is then  $33306 / 2260 = 14.74$  kJ per gram protein.

Oxidation of Kleiber's protein (Kleiber's protein contains 16.1% protein):  $C_{100}H_{159}N_{26}O_{32}S_{0.7} + 79.288 O_2 = 65.332 CO_2 + 39.779 H_2O + 8.667 N_3C_4H_9O_2$  (creatine) +  $0.7 H_2SO_4$

We can also assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Creatine contains 36.497% nitrogen, thus the oxidation of 1 gram of protein results in the formation of  $0.16 / 0.365 = 0.44$  grams of creatine. The energy density of 1 gram of creatine is 20.18 kJ, thus the energy of 0.44 grams of creatine is  $0.44 \times 20.18 = 8.88$  kJ and the available energy in 1 gram protein is then  $23.65 - 8.88 = 14.77$  kJ.

(f) Excretion of nitrogen in the form of a mixture of urea (90%), creatinine (5%) and ammonia (5%). We can assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Urea contains 46.6% N and 10.77 kJ per gram urea, creatinine contains 37.1%N and 20.66 kJ per gram creatinine and ammonia contains 82.2% N and 20.73 kJ per gram ammonia. Thus the loss of energy is  $((0.16 \times 0.90 / 0.466) \times 10.77) + ((0.16 \times 0.05) / 0.371) \times 20.66) + ((0.16 \times 0.05 / 0.822) \times 20.73) = 3.975$  kJ per gram protein. Thus the available energy of 1 gram of protein is  $23.65 - 3.975 = 19.68$  kJ per gram protein.

(g) Excretion of nitrogen in the form of a mixture of ammonia (85%) and urea (15%) as in fish. We can assume that protein in general contains 16% nitrogen. Thus the oxidation of 1 gram of protein results in the generation of 0.16 gram nitrogen. Ammonia contains 82.2% N and 20.73 kJ per gram ammonia and urea contains 46.6% N and 10.77 kJ per gram urea, Thus the loss of energy is  $((0.16 \times 0.85 / 0.822) \times 20.73) + ((0.16 \times 0.15 / 0.466) \times 10.77) = 3.98$  kJ per gram protein. Thus the available energy of 1 gram of protein is  $23.65 - 3.98 = 19.67$  kJ per gram protein in fish.

#### 14. Properties of logarithms:

$$\ln(a) + \ln(b) = \ln(ab)$$

$$\ln(a) - \ln(b) = \ln(a/b)$$

$$a \ln(b) = \ln(b)^a$$

$$\ln(a) \text{ means } e^{\ln(a)}.$$

$$g^{\log_a a} = a$$

proof:  $g^{\log_a a} = g^{\log_a a}$ , and thus, per definition:  $g^{\log_a a} = a$

$${}^a \log b = (\log b) / (\log a) \text{ or}$$

$$({}^a \log b) * (\log a) = (\log b)$$

proof:

$${}^a \log b = (\log b) / (\log a)$$

$$({}^a \log b) * (\log a) = (\log b)$$

$$(\log a)^{({}^a \log b)} = (\log b)$$

$$a^{({}^a \log b)} = b$$

or

$${}^a \log b = {}^a \log b \text{ (see above)}$$

$${}^a \log b = 1 / ({}^b \log a)$$

proof:

$${}^a \log b = {}^b \log b / {}^b \log a = 1 / ({}^b \log a)$$

when  $e^{\ln(a)} = b$ , then this means  $e^b = a$ ,

thus the anti - ln of b is a and is  $e^b$

$e = 2.71828$  (and with many more decimals !!) and can be calculated on a calculator as the anti - ln of 1.

#### Note

$$10^1 = 10$$

$$10^0 = 1$$

$$1^a = 1$$

$$\frac{1}{\infty} = 0$$

$$\frac{0}{1} = 0$$

$$\frac{1}{0} \text{ does not exist}$$

$0^a$  does not exist, and  $\log(0)$  does also not exist.

The logarithms of 0 and negative numbers do not exist.

$$\text{Anti - ln of } 1 = e = 2.71828 \text{ (} ^e\text{ln } e = 1)$$

**Further:**

$$10^5 * 10^3 = 10^{(5+3)} = 10^8$$

$$10^5 / 10^3 = 10^{(5-3)} = 10^2$$

$a/b = c/d$  then:  $a*d = b*c$  (cross-wise multiplication)

$$\sqrt[3]{10} = 10^{(1/2)} \text{ root is the inverse of the power}$$

$$10 / 2 = 10 * (1/2)$$

$$^2 \log 50 = a, \text{ then } 2^a = 50$$

$$^a \log a = 1 \text{ (} a^1 = a)$$

$$^a \log 1 = 0 \text{ (} a^0 = 1)$$

**The number e = 2.71:**

The derivative of  $y = ^a \log x = (1/x) ^a \log 2.71$

Thus, when  $a = 2.7$ , then the derivative of  $y = ^{2.71} \log 2.71 \cdot (1/x) = 1/x$

Thus, the derivative can be simplified by taking  $a = 2.71$  ( $^e \log = \ln$ , or the natural logarithm)