


DIGESTIBLE ENERGY AND PROTEIN REQUIREMENTS PER UNIT OF DAILY WEIGHT GAIN IN GROWING–FINISHING NILE TILAPIA REARED IN NET CAGES <https://doi.org/10.63330/aurumpub.043-009>**Thais Pereira da Cruz¹, Vitor André Frana² and Wilson Massamitu Furuya³****Abstract**

This study determined the digestible energy (DE) and digestible protein (DP) requirements per unit of daily weight gain (DWG) in growing–finishing Nile tilapia, *Oreochromis niloticus* reared in net cages over 210 days. Fish (n = 630; 45.9 ± 1.7 g as means ± standard deviation) were distributed into five floating net cages (1 m³ each) and fed extruded diet with 3,041 kcal/kg DE and 302.1 g/kg digestible protein (DP), three times daily, based on biomass. All fish were bulk weighed at the start and end, and data on feed intake and body weight (15 fish per net cage) were recorded every 36-day feeding trial. The relationship between DE and DP requirements for unit of daily weight gain (DWG) was best fit using linear regression: DE = 2.3185 + 0.4323 DWG and DP = 0.2303 + 0.0429 DWG. Both DE (3.4 to 5.7 kcal/ g DWG) and DP (0.34 to 0.57 g/g DWG) increased by 1.7-fold per unit of DWG for fish from 45.9 to 1,013 g body weight (BW) and revealed decreased dietary DE and DP utilization across BW increment of fish. These findings provide new insights into the relationship between dietary DE and DP requirements per unit of DWG in growing–finishing Nile tilapia production.

Keywords: Energy, Mathematical model, Protein, Requirement, *Oreochromis niloticus*.

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INTRODUCTION

INTRODUCTION OF THE TOPIC

Dietary digestible energy (DE) and digestible protein (DP) are two main dietary constituents that develop crucial role in growth performance and health of Nile tilapia, *Oreochromis niloticus* (El-Sayed, 2019; El-Sayed; Teshima, 1992; Fernandes et al., 2016; Koch et al., 2017; Peres et al., 2022) Knowledge of DE and DP relationship with daily weight gain (DWG) can support developing nutritional strategies to improve economic performance in growing–finishing Nile tilapia reared under industrial-scale. However, few studies have been conducted under field conditions to support these findings.

Nile tilapia culture has expanded to more intensive culture in many countries (FAO, 2024). However, modern nutritional practices demand precision nutrition practices to enhance economic dimensions and improve environmental sustainability (Fialho et al., 2021; Valenti et al., 2018). Recent studies have identified the use of artificial intelligence (AI) in field systems in modern aquaculture (Huang; Khabusi, 2025; Sen et al., 2026). Thus, predicting the DWG of growing–finishing Nile tilapia linking DE and DP intake and requirements using linear regression can favor the use of AI in precise Nile tilapia nutrition and feeding programs.

RESEARCH PROBLEM AND LIMITATION

Previous studies have applied complex factorial approach and advanced the estimation of DE and DP requirements for maintenance and production throughout the life cycle of Nile tilapia. Additionally, previous dose-response experiments were employed to determine DP intake and requirements in Nile tilapia (Castillo et al., 2017; Fernandes et al., 2016; Koch et al., 2017). Therefore, a simpler mathematical model can provide a more practical framework for estimating DE and DP required per unit of DW, thereby supporting broader application and precise nutrition practices.

Current knowledge on DE and DP is based on controlled laboratory research, which may not reflect results obtained in field conditions or fish, and may not reflect fish finding higher DWG across growing–finishing stages. Therefore, there is no field-based linear model information on DE and DP requirements as function of DWG, which limits the pattern in guidelines for Nile tilapia.

Linear regression analysis is an easy and robust way to estimate the DE and DP requirements in fish by directly relating nutrient intake to growth performance variables such as DWG, and is widely used to predict DP and available nutrient contents of feed ingredients (Sales, 2008), including Nile tilapia (Vitor et al., 2012). Unlike factorial models, which need multiple assumptions to distinguish between DE and DP requirements for maintenance and growth (Chowdhury et al., 2013; Van Trung et al., 2011), linear models can integrate biological responses under commercial production conditions. This approach can support the development of more precise and economically efficient feeding strategies and enable the estimation DE and DP requirements per unit of growth. Despite these advantages, no field-based linear models describe DE and DP requirements as a function of DWG in growing–finishing Nile tilapia, especially in long-term high-density net-cage production systems. This gap limits the application of precise nutrition and the development of practical guidelines for industrial scale feeding on an.

OBJECTIVES

This study aimed to establish the relationship between DE and DP requirements per unit of DWG in growing–finishing Nile tilapia reared in floating net cages in field conditions, using linear regression analysis. We hypothesized that DE and DP requirements increase with DWG in response of decreased efficiency in energy and protein utilization as fish BW and thereby DWG increase.

METHODOLOGY

ETHICS STATEMENTS

The Animal Care Committee of Universidade Estadual de Ponta Grossa research approved this experimental protocol (N° 25.000078777-8). Fish were anesthetized and euthanized using tricaine methanesulfonate (MS-222) at 100 and 400 mg/L water, respectively. Euthanasia procedure was complemented with physical penetrative captive method applied by specialized trained operators.

DIETS

A practical diet based on soybean meal protein to meet the dietary DE and DP (Clique ou toque aqui para inserir o texto. and amino acids (Rodrigues et al., 2020) requirements of growing–finishing Nile tilapia (**Table 1**). Feed ingredients were ground in hammer mill (sieve with 8-mm-diameter holes), mixed and single-screw extruded, and dried in rotary drum drier set to achieve an internal pellet temperature of 85 °C. Diets were extruded into 3.5-3.8 mm diameter floating pellets, with an acceptable floatability rate of at least 99.9%.

Table 1*Ingredient and analyzed composition of the experimental diets.*

Ingredients (fed-basis)	g/kg
Soybean meal	476
Corn meal	185
Wheat meal	120
Meat meal	54
Blood meal (Spray dried)	40
Soy oil	30
Corn starch	60
Broken rice	20
Mineral and vitamin mixture ^a	5
Salt	5
DL-methionine	2.5
L-lysine	2.5
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Analyzed composition (dry matter, g/kg)	
Dry matter	934.2
Gross energy (kcal/kg)	3,0410
Digestible energy (kcal/kg) ^b	320.1
Digestible protein ^b	302.1
Crude lipids	81.7
Crude fiber	32.5
Ash	32.4

^a Customized mixture of minerals and vitamins per kilogram of diet: Vitamin: A, 8,000 IU; D₃, 1,500 IU; E, 120 mg; K₃, 12 mg; B₁, 25 mg; B₂, 25mg; B₆, 25 mg; B₁₂, 0.10 mg; folic acid, 10 mg; pantothenic acid, 100 mg; ascorbic acid, 450 mg; biotin, 0.25 mg; choline, 1200 mg; niacin, 150 mg; Minerals: iron, 60 mg; copper, 5 mg; manganese, 25 mg; zinc, 30 mg; Iodina, 0.4 mg, cobalt, 0.25 mg; selenium, 0.2 mg.

^b Calculated digestible energy and digestible protein based apparent digestibility coefficients of feed ingredients (Boscolo; Hayashi; Meurer, 2002; Furuya et al., 2001; Gonçalves et al., 2009b, 2004; Guimarães et al., 2008; Guimarães; Pezzato; Barros, 2008; Pezzato et al., 2002; Vidal et al., 2017a, 2017b, 2015; Xavier et al., 2014). Gross energy or crude protein of crystalline amino acids (Rostagno; Albino, 2024) were fully transformed into their respective digestible values.

EXPERIMENTAL SETUP

Fish (n = 630; 45.9 ± 1.7 g; means ± standard deviation) from from a local company (GenoMar do Brasil Ltda, Londrina, PR, Brazil), were distributed into 5-1m³ (1 m × 1 m× 1m) floating net cages and fed extruded diet with 3,041 kcal/kg DE and 302.1 g/kg DP, and hand-fed three times daily, based on biomass (Lim, 1989) over 210-day feeding experiment. Feeding was stopped when a visible decrease in fish feeding activity was observed. Net cages were longitudinally allocated in the Chavantes reservoir (Carlópolis, PR), and feed intake was recorded daily. All fish were bulk weighed at the beginning and end of the experimental trial, and 15 fish from each net cage were grouped-weighted every 12 days to adjust feed allowance. Fish classes were established for every 36-day feeding trial.

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Water quality was monitored weekly using digital oximeter, and oxygen and temperature averaged 7.2 ± 0.9 and 28.3 ± 2.2 °C, respectively. Data on water alkalinity (40 ± 10 mg/L) and pH (7.3 ± 0.4 ; digital pH meter), as well as total ammonia and nitrite, were monitored monthly using commercial kits. Ammonia and nitrite were not detected during water quality analysis.

FEED CHEMICAL ANALYSIS

Feed samples were finely ground in hammer mill (0.5 mm diameter) and analyzed in accordance with the Association of Official Analytical Chemists (AOAC Int., 2005) methods, in triplicate, as follows: (1) dry matter were analyzed by oven-drying the samples at 105°C overnight; (2) crude protein (Nitrogen $\times 6.25$) was analyzed in micro-Kjeldahl; (3) crude lipid was performed using the chloroform: methanol method (Folch; Lees; Stanley, 1957); (4) crude fiber analyzed was conducted using sequential sulfuric acid, sodium hydroxide, combustion of organic matter at 600°C for 4 h, established by the Association of Official Analytical Chemists (AOAC, 1995), following combustion of organic matter; (5) ash analyzes was performed in muffle furnace set at 550°C for 6 h; (6) gross energy was determined in adiabatic bomb calorimeter, using benzoic acid as standardt.

CALCULATION

The relationship between DE and DP intake per unit of DWG was established as follows:

$$DWG = \frac{FBW - IBW}{36}$$

In which *DWG* is the daily weight gain (g/fish) and *FBW*, and *IBW* are the final and initial body weight (g/fish), respectively, determined at the end of each successive fish sampling, and 36 represents the time intervals (days) between successive weightings.

$$Nt = FI \times Nc$$

In which Nt is total digestible energy or digestible protein intake (kcal or g), FI is daily feed intake (g/fish), Nc is digestible energy or digestible protein content (kcal or g) per gram of diet.

$$Ndwg = \frac{Nt}{DWG}$$

In which $Ndwg$ is digestible energy or digestible protein intake (kcal or g) per kilogram of daily weight gain, Nt is total digestible energy or digestible protein intake (g/fish), DWG is daily weight gain (g)

STATISTICAL ANALYSIS

The relationship between DE and DP intake and DWG was established using linear regression for linear or quadratic effects as follows:

$$y = a + b_1x_1 + e$$

In which y is DE or DP intake criteria, a is the intercept, b_1 is the slope of DWG, and x_1 is DWG, and e is the aleatory error. The precision of the mathematical model was evaluated using the correlation coefficient (Lin, 1989). Statistical differences were considered significant with $P < 0.05$. The data for each response were analyzed using Minitab (version 19, Minitab, Inc., State College, PA, USA).

RESULT AND DISCUSSION

Data on growth, DE, and DP intake are shown in Table 2. These findings indicate that the DWG and feed intake patterns align previously reported results in Nile tilapia reared in floating net cages

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(Fialho et al., 2021). However, several water quality variables, particularly temperature and dissolved oxygen contents, can affect feed intake and thereby DWG in Nile tilapia (Abd El-Hack et al., 2022).

Table 1

Growth, energy, and protein intake in growing–finishing Nile tilapia reared in floating net cages over 216-day feeding trial.*

BWC	MBW	DWG	FIN	DE	DP
0.05 to 0.14	0.09 + 0.00	2.5 + 0.2	2.8 + 0.1	3.4 + 0.1	0.34 + 0.01
0.14 to 0.28	0.21 + 0.02	4.0 + 0.2	5.2 + 0.1	4.0 + 0.0	0.40 + 0.01
0.28 to 0.50	0.39 + 0.014	6.2 + 0.4	9.6 + 0.5	4.7 + 0.2	0.47 + 0.02
0.50 + 0.76	0.63 + 0.02	7.0 + 0.5	12.2 + 0.3	5.3 + 0.1	0.52 + 0.01
0.76 + 1.00	0.88 + 0.01	6.9 + 0.2	12.9 + 0.1	5.7 + 0.0	0.57 + 0.00

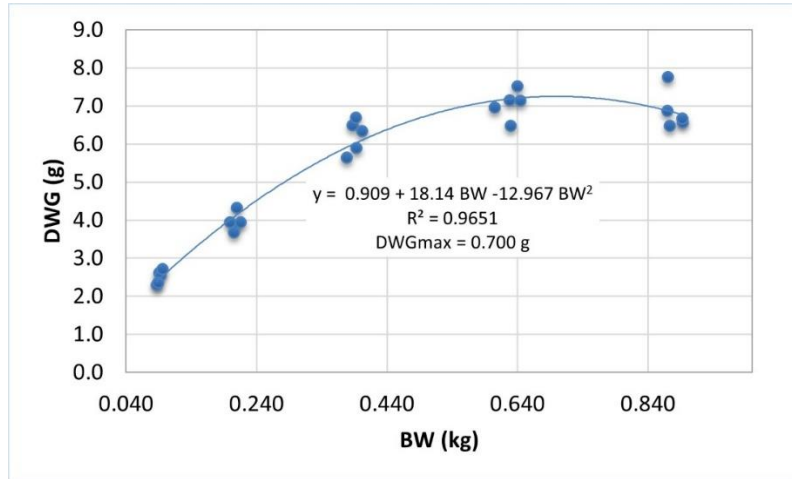
Abbreviations: BWC, body weight class (kg), mean body weight gain (g); FIN, feed intake (g/fish/day), DE, digestible intake per gram of body weight gain; DP, digestible protein intake per gram of body weight gain.

*Values are mean ± standard error of the mean of five replicates.

According to Figure 1, DWG reached a maximum value in fish with 0.7 kg BW and then decreased. A reasonable hypothesis is that this decline may be linked to reduced feed allowance in larger Nile tilapia (BW > 0.7 kg), a practical management strategy adopted to address declining feed efficiency and improve feeding cost. This phenomenon was previously reported in Nile tilapia raised under indoor experimental conditions (Chowdhury et al., 2013). Another plausible explanation is that the DE requirements for maintenance increase with each increment in BW. This hypothesis has been described in Nile tilapia from 10 to 800 g, where the proportion of DE allocated to maintenance increased from 8 to 14% of total DE requirement, respectively (Van Trung et al., 2011)

Figure 1

View of quadratic relationship between daily weight gain (*DWG*) as function of body weight (*BW*) in growing–finishing Nile tilapia reared in floating net cages over 216-day feeding trial. Each dot point is mean of each replicate floating net cage with 126 fish.



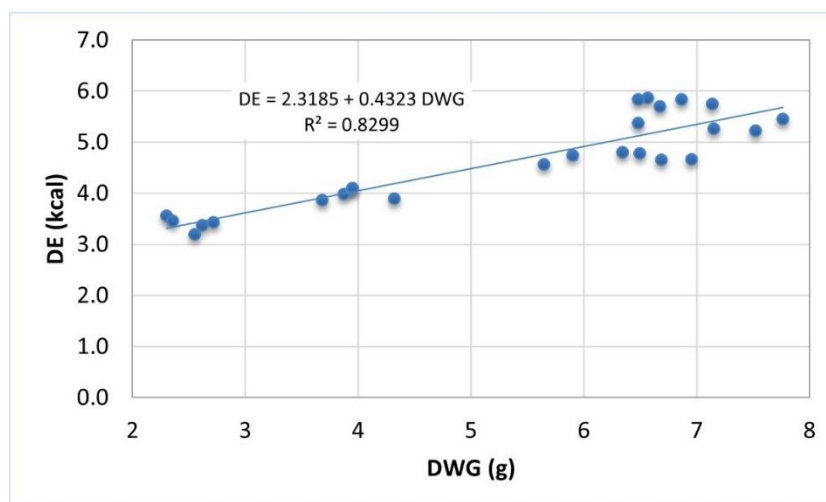
The linear relationship between DE intake and DWG in growing–finishing Nile tilapia was best established according to the expression, also presented in Figure 2:

$$DE = 2.3185 + 0.4323 DWG$$

In which *DE* is digestible energy intake (kcal), and *DWG* is daily weight gain (g/fish).

Figure 2

Linear relationship between digestible energy (DE) intake and daily weight gain (DWG). View of quadratic relationship between daily weight gain (DWG) as function of body weight (BW) in growing–finishing Nile tilapia reared in floating net cages over 216-day feeding trial. Each dot point is mean of each replicate floating net cage with 126 fish.



The increase in DE intake as function of increment in DWG indicates reduction in dietary DE utilization efficiency as BW increases. A previous study has reported linear increase in whole-body lipid deposition in Nile tilapia from 2 to 800 g (Chowdhury et al., 2013). Since lipids possess more energy per unit than protein, the increase in whole-body lipids likely contributes to the DE required per unit of DWG observed herein.

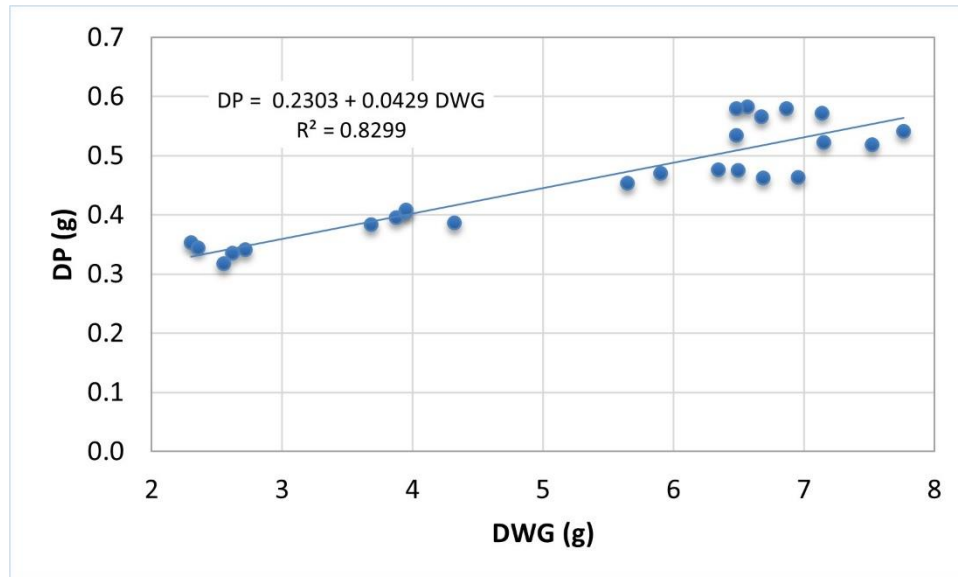
The relationship between DP intake and DWG was expressed according to the expression, also demonstrated in Figure 3:

$$DP = 0.2303 + 0.0429 DWG$$

In which *DP* is digestible protein intake (g), and *DWG* is daily weight gain (g/fish).

Figure 3

Linear relationship between digestible protein (DE) intake and daily weight gain (DWG). View of quadratic relationship between daily weight gain (DWG) as function of body weight (BW) in growing–finishing Nile tilapia reared in floating net cages over 216-day feeding trial. Each dot point is mean of each replicate floating net cage with 126 fish.



Similar to the patterns observed for DE, this study identified an increase in DP in intake per unit increment in DWG of fish. This result suggests reduction in protein utilization efficiency as BWG increases. This phenomenon may be explained by increased protein demand for maintenance in larger fish, as observed in Nile tilapia ranging from 10 to 1000 g BW, where the proportion of dietary DP allocated to maintenance increased from 4 to 18%, respectively (Van Trung et al., 2011). Nonetheless, these authors also found that the proportion of dietary DP allocated for gain decreased from 50 to 42% in fish weighing 10 and 1000 g BW, respectively. These results support the use of precise nutrition concepts to optimize growth performance and health, while aligning economic efficiency with environmentally sustainable practices. These demands have been recently recognized in the application of AI in field-based tilapia aquaculture (Huang; Khabusi, 2025; Sen et al., 2026).

This study identified a strong correlation coefficient (0.8299) between observed and estimated values of DE and DP as function of DWG, indicating that the linear model fitted well and generated reliable estimates. Notably, the reduced DE and PD efficiency utilization with increasing BW evidence

the need to consider economic responses and environmental impacts when rearing fish exceeding 700 g BW. These findings further support the use of precise feed formulation and feeding strategies in modern, industrial-scale tilapia field-based Nile tilapia production systems.

CONCLUSION

This study developed reliable and practical equations that establish the relationship between digestible energy and digestible protein intake as function of daily weight gain in growing–finishing Nile tilapia. Furthermore, increment in BW was associated with higher digestible energy and digestible protein requirements per unit of daily weight gain, evidenced by reduced energy and protein efficiency utilization as fish body weight increased. These findings highlight the need to account for increased feed cost and potential impact when rearing fish over 700 g body weight. These results provide new insights into precise nutrition practices aligned with environmentally sustainable strategies in modern Nile tilapia aquaculture systems.

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