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EVALUATION OF SIX PRACTICAL TILAPIA DIETS FROM
SEVERAL COUNTRIES USING A SATURATION KINETIC MODEL

By

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ABSTRACT

EVALUATION OF SIX PRACTICAL TILAPIA DIETS FROM SEVERAL COUNTRIES USING A SATURATION KINETIC MODEL

The primary objective of this study was to demonstrate that a saturation kinetic model can be used to describe the diet (nutrient) response relationship in fish. Five practical tilapia feeds from Honduras, Thailand, Panama, Indonesia, and the United States containing different levels of gross energy and other nutrients were each fed at ten graded levels to the three replicate groups of O. niloticus fingerling (mean weight 3g). Ten fish per group were tested for five weeks in ten gallon aquaria designed to prevent fish from ingesting their feces. Feed intake levels were 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 5.0, and 7.0 percent of the fish live wet weight per day divided into two equal feedings adjusted weekly.

The dietary (nutrients)-response of the five practical tilapia diets fit the saturation Kinetic model. O. niloticus weight gain and net nutrient (crude protein, gross energy, crude fat, calcium, phosphorus, magnesium and zinc) deposition were described as a function of the dietary (nutrient) intake graphically and numerically.

Comparisons of the five diets and their nutrients to promote O. niloticus weight gain or net nutrient deposition are based on

parameters calculated from the saturation kinetic model: 1) $R_{\max}$ (maximum response of O. niloticus fingerlings as a result of feeding a specific diet or nutrient, 2) $K0.5$ (dietary nutrient intake level that produced half maximum response by the fish), 3) $I_r=0$ (the dietary or nutrient intake at maintenance level (no gain or loss)).

Application of the model provided useful comparisons of diets (nutrients) as well as information concerning maximum efficiency, overall efficiency, and rates of diet (nutrient) utilization from different sources. If price information were available the diets could have been evaluated economically based on various feeding regimes. Price times $R_{\max}$ feeding level or maximum efficiency would provide valuable cost/benefit information.

DEDICATION

To my father and late mother, sincerest gratitude for their
constant love and support.

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TABLE OF CONTENTS

	PAGE
LIST OF TABLES.....	vi
LIST OF FIGURES.....	xi
 CHAPTER	
I. INTRODUCTION.....	1
II. LITERATURE REVIEW.....	5
Protein Requirements for Tilapias.....	19
Energy Requirements for Tilapias.....	20
Essential Fatty Acids.....	24
Dietary Carbohydrate.....	26
Minerals.....	27
III. MATERIALS AND METHODS.....	30
Cultural Conditions.....	30
Fish.....	31
Fish Feeds.....	31
Feeding Trials.....	32
Chemical Analysis.....	33
Mathematical and Statistical Analysis.....	33
IV. RESULTS.....	37
Dietary Analysis.....	38
Growth.....	40
Net Energy Deposition.....	53
Crude Protein Response.....	66
Crude Fat Deposition.....	78
Dietary Minerals Content of the Test Diets.....	91
Dietary Calcium Response.....	91
Dietary Magnesium Response.....	105
Dietary Zinc Response.....	118
Dietary Phosphorus Response.....	130

TABLE OF CONTENTS (Continued)

	PAGE
V. DISCUSSION.....	144
Growth.....	146
Energy Deposition.....	149
Dietary Protein Response.....	150
Dietary Crude Fat Deposition.....	152
Magnesium Deposition.....	153
Dietary Calcium Deposition.....	154
Zinc Deposition.....	154
Dietary Phosphorus Deposition.....	155
VI. SUMMARY AND CONCLUSION.....	157
LITERATURE CITED.....	159
APPENDIX I.....	170

LIST OF TABLES

TABLE		PAGE
1.	Protein requirements (%) for maximum growth of different tilapias of various size groups (from El-Sayed 1987).....	21
2.	Dietary energy and protein requirements of <u>Tilapia zillii</u> at different feeding rates and experimental durations.....	22
3.	Calculated energy distribution of protein catabolized by ammonotelic, ureotelic, and uricotelic animals (Smith, et al. 1978).....	23
4.	Dietary protein to energy ratios requirements for different species of tilapias (modified from El-Sayed 1987).....	25
5.	Proximate analysis of the five Tilapia diets (AOAC 1980).....	39
6.	Total food intake, weight gain (ro), and the theoretical response (rc) of <u>O. niloticus</u> fed varying percentages of the Honduran tilapia feed.....	41
7.	Total food intake, weight gain (ro), and the theoretical response (rc) of <u>O. niloticus</u> fed varying percentages of the Thailand tilapia feed.....	42
8.	Total food intake, weight gain (ro), and the theoretical response (rc) of <u>O. niloticus</u> fed varying percentages of the Panamanian tilapia feed.....	43
9.	Total food intake, weight gain (ro), and the theoretical response (rc) of <u>O. niloticus</u> fed varying percentages of the Indonesian tilapia feed.....	44

LIST OF TABLES (Continued)

PAGE

10. Total food intake, weight gain (ro), and the theoretical response (rc) of O. niloticus fed varying percentages of the U.S. tilapia feed..... 45
11. Parameters derived from fitting intake and weight gain per gram of fish/five week period as a function of food intake level as a percentage of fish body weight..... 51
12. Total (gross) energy intake, observed deposition (ro), and calculated energy deposition (rc) of O. niloticus fed varying percentages of the Honduran tilapia feed..... 54
13. Total (gross) energy intake, observed deposition (ro), and calculated energy deposition (rc) of O. niloticus fed varying percentages of the Thailand tilapia feed..... 55
14. Total (gross) energy intake, observed deposition (ro), and calculated energy deposition (rc) of O. niloticus fed varying percentages of the Panamanian tilapia feed..... 56
15. Total (gross) energy intake, observed deposition (ro), and calculated energy deposition (rc) of O. niloticus fed varying percentages of the Indonesian tilapia feed..... 57
16. Total (gross) energy intake, observed deposition (ro), and calculated energy deposition (rc) of O. niloticus fed varying percentages of the U.S. tilapia feed..... 58
17. Parameters derived from fitting dietary gross energy (kcal/g/five weeks) intake and total energy deposition kcal per fish for a five-week period..... 64
18. Crude protein intake, observed deposition (ro), and calculated deposition (rc) of O. niloticus fed varying percentages of the Honduran tilapia feed..... 67
19. Crude protein intake, observed deposition (ro), and calculated deposition (rc) of O. niloticus fed varying percentages of the Thailand tilapia feed..... 68
20. Crude protein intake, observed deposition (ro), and calculated deposition (rc) of O. niloticus fed varying percentages of the Panamanian tilapia feed.... 69

LIST OF TABLES (Continued)

	PAGE
21. Crude protein intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Indonesian tilapia feed....	70
22. Crude protein intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the U.S. tilapia feed.....	71
23. Parameters derived from fitting dietary protein intake (mg protein/g of fish/five-week period) and protein deposition (mg protein/g fish/five-week period) for each of the five tilapia practical diets.....	77
24. Crude fat intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Honduran tilapia feed.....	79
25. Crude fat intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Thailand tilapia feed.....	80
26. Crude fat intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Panamanian tilapia feed.....	81
27. Crude fat intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Indonesian tilapia feed.....	82
28. Crude fat intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the U.S. tilapia feed.....	83
29. Parameters derived from the model equation for dietary crude fat deposition vs dietary crude fat intake (mg/g fish/five weeks).....	89
30. Calcium, phosphorus, magnesium and zinc analysis of the tested diets (AOCA 1975).....	92
31. Magnesium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Honduran tilapia feed.....	93

LIST OF TABLES (Continued)

PAGE

32.	Magnesium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Thailand tilapia feed.....	94
33.	Magnesium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Panamanian tilapia feed.....	95
34.	Magnesium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Indonesian tilapia feed.....	96
35.	Magnesium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the U.S. tilapia feed.....	97
36.	Parameters derived from fitting magnesium intake (mg/g fish initial weight/five-week) and magnesium deposition (g/g fish/five-week period.....	103
37.	Calcium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Honduran tilapia feed.....	106
38.	Calcium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Thailand tilapia feed.....	107
39.	Calcium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Panamanian tilapia feed.....	108
40.	Calcium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the Indonesian tilapia feed.....	109
41.	Calcium intake, observed deposition (ro), and calculated deposition (rc) of <u>O. niloticus</u> fed varying percentages of the U.S. tilapia feed.....	110
42.	Parameters derived from dietary calcium levels (mg/g fish initial weight/five weeks) and calcium deposition (mg/g fish/five-week period).....	116

LIST OF TABLES (Continued)

PAGE

43. Zinc intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the Honduran tilapia feed.....119
44. Zinc intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the Thailand tilapia feed.....120
45. Zinc intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the Panamanian tilapia feed.....121
46. Zinc intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the Indonesian tilapia feed.....122
47. Zinc intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the U.S. tilapia feed.....123
48. Parameters derived from dietary zinc intake levels (μ /g fish initial weight/five weeks) and zinc deposition (μ /g fish/five-week period).....129
49. Phosphorus intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the Honduran tilapia feed.....131
50. Phosphorus intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the Thailand tilapia feed.....132
51. Phosphorus intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the Panamanian tilapia feed.....133
52. Phosphorus intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the Indonesian tilapia feed.....134
53. Phosphorus intake, observed deposition (ro), calculated deposition (rc) of O. niloticus fed varying percentages of the U.S. tilapia feed.....135
54. Parameters derived from dietary phosphorus levels (mg/g fish initial weight/five weeks) and phosphorus deposition (mg/g fish/five-week period).....141

LIST OF FIGURES

FIGURE		PAGE
1.	Utilization of a nutrient in the production of a physiological response (Mercer 1982).....	12
2.	Theoretical nutrient response curve of feed intake vs weight gain deposition of <u>O. niloticus</u> fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group means, n=3).....	46
3.	Theoretical nutrient response curve of feed intake vs weight gain deposition of <u>O. niloticus</u> fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group means, n=3).....	47
4.	Theoretical nutrient response curve of feed intake vs weight gain deposition of <u>O. niloticus</u> fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....	48
5.	Theoretical nutrient response curve of feed intake vs weight gain deposition of <u>O. niloticus</u> fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group means, n=3).....	49
6.	Theoretical nutrient response curve of feed intake vs weight gain deposition of <u>O. niloticus</u> fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group means, n=3).....	50
7.	Theoretical nutrient response curve of total energy intake vs total energy deposition of <u>O. niloticus</u> fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....	59
8.	Theoretical nutrient response curve of total energy intake vs total energy deposition of <u>O. niloticus</u> fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....	60

LIST OF FIGURES (Continued)

PAGE

9. Theoretical nutrient response curve of total energy intake vs total energy deposition of O. niloticus fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)..... 61
10. Theoretical nutrient response curve of total energy intake vs total energy deposition of O. niloticus fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)..... 62
11. Theoretical nutrient response curve of total energy intake vs total energy deposition of O. niloticus fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)..... 63
12. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of O. niloticus fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)... 72
13. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of O. niloticus fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)... 73
14. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of O. niloticus fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)... 74
15. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of O. niloticus fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)... 75
16. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of O. niloticus fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)..... 76
17. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of O. niloticus fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)..... 84

LIST OF FIGURES (Continued)

PAGE

18. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of O. niloticus fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$)..... 85
19. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of O. niloticus fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$)..... 86
20. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of O. niloticus fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$)... 87
21. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of O. niloticus fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$)..... 88
22. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of O. niloticus fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$)..... 98
23. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of O. niloticus fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$)..... 99
24. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of O. niloticus fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).....100
25. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of O. niloticus fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).....101
26. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of O. niloticus fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).....102
27. Theoretical nutrient response curve of calcium intake vs calcium deposition of O. niloticus fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).....111

LIST OF FIGURES (Continued)

PAGE

28. Theoretical nutrient response curve of calcium intake vs calcium deposition of O. niloticus fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....112
29. Theoretical nutrient response curve of calcium intake vs calcium deposition of O. niloticus fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....113
30. Theoretical nutrient response curve of calcium intake vs calcium deposition of O. niloticus fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....114
31. Theoretical nutrient response curve of calcium intake vs calcium deposition of O. niloticus fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....115
32. Theoretical nutrient response curve of zinc intake vs zinc deposition of O. niloticus fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....124
33. Theoretical nutrient response curve of zinc intake vs zinc deposition of O. niloticus fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....125
34. Theoretical nutrient response curve of zinc intake vs zinc deposition of O. niloticus fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....126
35. Theoretical nutrient response curve of zinc intake vs zinc deposition of O. niloticus fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....127
36. Theoretical nutrient response curve of zinc intake vs zinc deposition of O. niloticus fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....128
37. Theoretical nutrient response curve of phosphorus intake vs phosphorus deposition of O. niloticus fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....136

LIST OF FIGURES (Continued)

	PAGE
38. Theoretical nutrient response curve of phosphorus intake vs phosphorus deposition of <u>O. niloticus</u> fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....	137
39. Theoretical nutrient response curve of phosphorus intake vs phosphorus deposition of <u>O. niloticus</u> fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3)....	138
40. Theoretical nutrient response curve of phosphorus intake vs phosphorus deposition of <u>O. niloticus</u> fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....	139
41. Theoretical nutrient response curve of phosphorus intake vs phosphorus deposition of <u>O. niloticus</u> fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).....	140

CHAPTER I

INTRODUCTION

Tilapia (Appendix 1) probably have been raised as a source of human food for over 4500 years. The harvest of Tilapia was illustrated on an Egyptian tomb dating back to 2500 B.C. (Bardach et al. 1972). In the 1900's and particularly the last 40 years, Tilapia have been transplanted from Africa and the Middle East to many countries around the world. Tilapia have become a major source of protein in many of the developing countries (Pullin and Lowe-McConnel 1982).

Tilapia demonstrate a rapid growth rate on low protein diets compared to many other cultured fishes. They are efficient in utilizing poor quality natural food such as blue green algae. Tilapia tolerate a wide range of environmental conditions such as water temperatures and dissolved oxygen levels (Pullin and Lowe-McConnel 1982). Under intensive culture, their production can be as high as 70-100 kg/hectare/day without a loss in food conversion. This efficiency is due to the Tilapia's excellent utilization of artificial feed and natural food (Allison et al 1976; Tal and Ziv 1978; Rakocy and Allison 1980).

Efforts to produce high quality animal protein for human consumption through aquaculture often have been directed toward

intensive fish production using formulated foods (King and Garling 1983). In fish nutrition research, therefore, efforts have been directed towards development of standardized methodology (Smith 1971 and Cho et al. 1982) to detect small differences in fish diet or nutrient quality. Many of these efforts were unsuccessful. Classical animal nutrition methods are not directly adaptable to fish as will be discussed later. Therefore, new techniques are needed to evaluate dietary nutrients for fish (Tilapia).

According to the National Research Council (1981) inexpensive computers and programmable calculators will promote development of sophisticated models to predict comparative feed value, specific animal requirements, and the prediction of the production response of fish to a particular diet. Feeds would be evaluated on the basis of how they supply energy and nutrients for a specific fish's production response in comparison to the other feeds available at the same time. Feeds would be evaluated, diets formulated, and animal response predicted by relatively complex computer programs that would use a detailed chemical and physical description of each feed and a knowledge of the biochemical, physiological and physical processes involved in animal metabolism.

A general equation based on physiological responses to different environmental factors was developed by Morgan et al. (1975). This model is based on the interaction between a dependent variable, the observed response (r), and an independent variable, nutrient intake (I), which is described by the equation:

$$r = (bKi + R_{\max}I^n)/(Ki + I^n)$$

Where:

r = observed response of the organism (body weight gain or nutrient deposition at specific intake level per day)

I = nutrient intake

b = ordinate intercept

$R_{\max}$ = maximum response

n = slope factor apparent kinetic order of the response with respect to I as I^n becomes negligible compared to K_I).

K_I = nutrition constant

This model is based on the enzyme kinetic equations (Michaelis-Menten 1913 and Hill 1913). This model has been experimentally tested as a nutritional indice on many animals (rats, mice, chickens, turkeys, and man) in measuring weight gain, net nutrient deposition, dietary requirements, tissue enzyme levels, plasma nutrient levels and others (Mercer 1980).

The model (Morgan et al. 1975) provides a continuous response curve. It can be used as a predictive nutritional model which could be expanded to provide an economic analysis of fish diets. The model

will enable the quantitative assessment of aquaculture feeds in many of the developing countries. It provides a full dietary evaluation in a short period of time (five weeks) using equipment that is available in most of the developing countries. It will, hopefully, aid such international organizations as the Food and Agriculture Organization (FAO) and the United States Agency for International Development (USAID) in attaining their goal of increasing animal protein consumption in the world.

The present study was carried out to compare six practical Tilapia feeds used in Egypt, Honduras, Panama, Indonesia, Thailand and the United States. Diets from Honduras, Panama, Indonesia and Thailand were provided by participants in the United States Agency for International Development (USAID) Title XII Collaborative Research Support Project (CRSP) in Pond Dynamics Aquaculture. The four parameters (b , K , I , N , $R_{\max}$) were estimated for growth, crude protein deposition, crude fat deposition, gross energy accumulation, total mineral deposition, and specific minerals (calcium, phosphorus, magnesium and zinc) for comparison between all diets. Each diet was fed to O. niloticus fingerlings at ten food intake levels (3 replicate tanks/intake level/feed) for a period of five weeks. The quantitative predictive curves were computer generated using a computer program provided by Dr. L. Preston Mercer (personal communication, Department of Biochemistry, School of Medicine and Dentistry, Oral Roberts University, Tulsa, Oklahoma) and compared statistically using multiple nonlinear regression analysis (Draper and Smith 1966).

CHAPTER II

LITERATURE REVIEW

Dietary evaluation of animal growth depends upon a simple relationship that was developed by Winberg (1956) that is referred to as the Energy Balance Equation:

$$\text{Ration (x absorption factor)} = \text{metabolism} + \text{growth}$$

Absorption factor (digestability coefficient) and/or metabolism are essential in evaluating fish diets in terms of growth (weight gain per unit of time). The apparent digestability coefficient for any nutrient and/or gross energy can be determined in vivo by the "Direct Method" (the total collection technique). This technique relies on quantitative measurement of the ingested (food) and egested (feces) materials used in the equation:

$$D\% = \frac{I - E}{I}$$

Where:

D% = the percentage digestability

I = amount of nutrient ingested

E = amount of nutrient egested

A second technique for measuring the apparent digestability coefficient is called the "Indirect Method" or the "Indicator Method." An external indicator is a indigestible substance that is added to the test diet in a small quantity (1-2%). An internal indicator is a naturally occurring nondigestable component in a diet as a constant proportion. Indicators should not affect digestion or palatability of the test diet. Additionally, their concentration should be easily determined. The percentage of the indicator is measured in the food and a sample of the feces to estimate the digestability coefficient by the equation:

$$\text{Digestibility} = 100 - \left(100 \times \frac{\% \text{ indicator in the food}}{\% \text{ indicator in the feces}} \right)$$

Errors in quantitative fecal collection is a major source of under or over-estimation of the digestability coefficient. The quantitative measurements of egested materials is difficult under aquatic environmental conditions without accepting a level of significant error. The major source of error is fecal leaching in the water and/or fish stress depending on the collection technique.

There are several methods to collect fish feces: 1) dissecting the fish gut after sacrificing the fish and collecting its fecal materials; 2) manual stripping of live fish from the abdominal cavity to obtain a fecal sample; 3) anal suctioning (Windell et al. 1978); 4) collecting feces deposited in the aquarium using a fine dip net (Windell et al. 1974); 5) siphoning the feces using a specially

designed aquarium (Buddington 1980); 6) settling columns attached to the aquarium drain system (Cho et al. 1975); 7) the mechanically rotating filter screen (Choubert et al. 1982); 8) the metabolism chamber (Smith 1971).

Techniques 1, 2, and 3 were developed to overcome the problem of leaching by collecting feces directly from the intestinal tract of the fish. These three procedures have caused underestimation of the digestion coefficient since incompletely digested materials mixed with body fluid, intestinal epithelium, and excess enzymes were collected along with the fecal sample (Cho et al. 1982). Additionally, gastric motility was probably affected by force feeding fish used in the experiment. Force feeding reduced the evacuation rate in walleye (Stizostedion Vitreum Vitreum) by one-half over voluntary feeding (Windell et al. 1966).

Cho et al. (1975) used tanks measuring 55 x 10 x 35cm with a sloping bottom. A drain pipe is connected to the sloping bottom and to a stand pipe positioned over an acrylic settling column (10cm dia x 40cm high). Fish are freely fed in this system for 9-16 hours. The tanks are then cleaned of food particles by draining and replacing one-third of the tank's water. After a feeding period, feces are collected for 9-16 hours. At the end of the collection period the settling column is opened and the feces are removed. Choubert et al. (1982) collected fish feces from the tank drainage water by passing the water through a moving metallic screen. Feces were removed mechanically from the water by the screen.

In methods 4, 5, 6, and 7 leaching of dissolved materials into the water is the single major error which causes over-estimation of digestibility. When fecal samples were kept in the water for only one hour, the digestability for dry matter, protein and lipids dropped by 11.5 percent, 10 percent, and 3.7 percent, respectively (Windell et al. 1978).

Smith (1971) developed a metabolism chamber to permit separate and quantitative collection of feces, urine, and gill excretions. The fish are confined in a tube. The water surrounding the fish in the front of the chamber (5 gallon) is separated by a rubber dam from the rear of the chamber. Urine is collected through a catheter into a bottle outside the chamber. The fish are force fed a measured amount of feed daily. After a three-day adaptation period, waste collection is made for four or five days. Fish are anesthetized during handling and force feeding. This method is used to measure digestibility and metabolizability. Stress caused by confinement, anesthesia, and force feeding is the major problem associated with this procedures. Stress inhibits absorption (Shadler 1979), causes hyperglycemia, elevates muscle blood lactate, serum cholesterol, skin mucus secretion, and oxygen consumption (Love 1980). Smith (personal communication) claimed that stress was reduced to "normal" levels by injecting pure oxygen into the metabolic chamber to reduce blood lactate. However, blood lactate is not a good indicator of confinement stress since lactic acidosis results from anaerobic muscle glycolysis (Wedemeyer 1976). Other more appropriate stress indicators were not measured.

The second part of Winberg's equation for dietary evaluation is metabolism. Several methods have been developed to measure the energy budget of fish. In 1976, Smith modified adiabatic calorimetry for use with fish. He utilized the direct calorimetry procedure (Hill 1911) which is based on measuring heat production using thermal equivalent. Smith (1976) reported that the direct calorimetry method is less sensitive to metabolic fluctuations when compared to indirect calorimetry using the oxygen consumption method (Brett 1979). The indirect calorimetry method measures the amount of oxygen consumed during a specific period of time multiplied by an oxycalorific equivalent. Application of this method assumes that dietary nutrients such as carbohydrates, lipids, and proteins are being digested and metabolized in the same proportion which they occur in the diet (Brafield 1985). This assumption is due to the difficulty of measuring fecal, urine, and gill excretions. Additionally, this procedure ignores anaerobic metabolism.

The indirect calorimetry method can be improved by using oxygen, carbon dioxide and ammonia (Brafield & Llewellyn 1982). The application of this method is based upon accurately measuring the oxygen consumption, ammonia production, and carbon dioxide production. Unfortunately, large amounts of carbon dioxide can be present in the water (especially hard water) which, in turn, suppresses the release of carbon dioxide from fish (Kutty 1968). Ammonia excretion by fish is also affected by the concentration of ammonia in the water (Goldstein et al. 1982).

Due to the complexity and the difficulty of measuring the metabolizability of nutrients, the net deposition or growth (the last part of the Winberg equation) has been used to evaluate fish diets and establish the nutrient requirements of fish. The most commonly applied growth model for dietary evaluation has been the linear model or straight-line equation.

$$Y = a_0 + a_1 X \quad 1$$

This model is easy to use and valuable in describing the nutritional response over a linear range of response of nutritional intake. Over a wide intake range of nutrient intakes, the growth response, however, is not linear. Therefore, the logarithmic form of equation 1 used to describe the curvilinear relationship over a wide range of nutrient intake equation 2:

$$Y = a_0 + a_1 \log X \quad 2$$

At very low levels of nutrient intake, the biological response appears to deviate from the principle (Almquist 1953).

Hegsted and Neff (1970) observed that linear equations are sufficient for the middle area of the response curve, but at higher nutrient inputs an extra parameter of the quadratic model became significant:

$$Y = a_0 + a_1 X + a_2 X^2$$

3

However, the quadratic model is still inadequate in describing the lower end of the biological curve. If another parameter is added to equation 3, the equation will not satisfy the criterion of a mathematical or a biological significance (Mercer 1980). A new model was developed by Morgan et al (1975) based on the enzyme kinetic equation (Michaelis-Menten 1913 and Hill 1913). The theoretical derivation of this model was developed by Mercer (1982). The effects of a nutrient in a physiological system may be regarded as the results of physicochemical interactions between the nutrient and various macromolecular components of the organism. These specific interactions give use to organize functions which collectively are described as the metabolic activity or responses of the organisms.

It is possible to conceptualize a sequence of events by which a nutrient elicits its characteristic response. This sequence is shown in Figure 1. Almost every aspect of nutrient utilization is mediated by specific interactions with a macromolecule such as an enzyme. If one assumes that there is a rate-limiting step in the sequence, then the magnitude of response would be a function of the rate-limiting step. Such a rate-limiting step has been postulated by Almquist (1953). The interaction of the nutrient with a specific site on the macromolecule (receptor) would give rise to a physiological response and the magnitude of the response would be directly proportional to

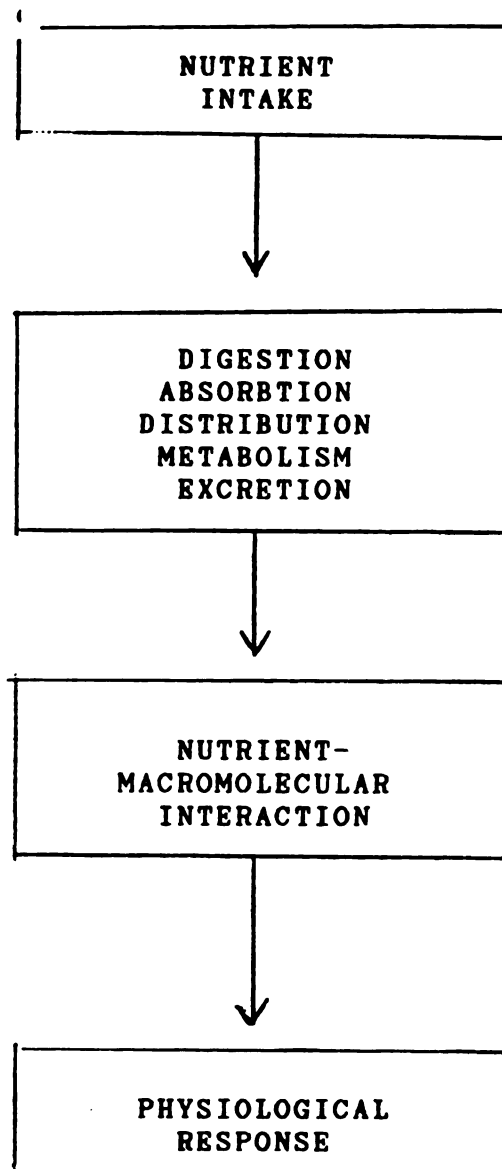
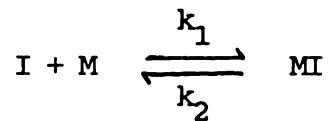


Figure 1. Utilization of a nutrient in the production of a physiological response (Mercer 1982).

the number of receptors occupied by the nutrient. This concept allows one to apply the law of mass action to the system and derive an appropriate equation governing the quantitative relationship between nutrient and response.

In the following example, a nutrient, (I), combines with a receptor, (M), to yield the complex MI which produces the physiological response pr in a manner proportional to concentration of MI:



$$pr = k_3 [MI]$$

(where K_1 , k_2 , and K_3 are constants and $[]$ denotes concentration)

At equilibrium:

$$\frac{[M][I]}{[MI]} = \frac{k_2}{k_1} = K_I$$

(where K_I is also a constant)

Next, if M_t is defined as the total receptor concentration so that $[M_t] = [M] + [MI]$, then:

$$\frac{[Mt - Mi] [I]}{[MI]} = K_I$$

Rearrangement gives:

$$\frac{[MI]}{[Mt]} = \frac{[I]}{K_I + [I]}$$

If $PR_{\max}$ is the maximal physiological response of the system when all receptors are occupied:

$$PR_{\max} = k_3 [Mt]$$

then:

$$\frac{pr}{PR_{\max}} = \frac{[MI]}{[Mt]}$$

and

$$pr = \frac{PR_{\max}[I]}{K_I + [I]}$$

4

This equation is identical to the Michaelis-Menten equation (Hegsted and Neff 1970) and could be useful in describing physiological responses to nutrients, based on the model in Figure 1.

It meets the criteria of observed phenomena, that is a continuous response to graded levels of intake and the law of diminishing returns (Almquist 1953).

However, equation 4 has two limitations which do not coincide with observed responses. First, the equation only describes a hyperbola, while many responses are found experimentally to be sigmoidal ($n > 1$) in nature (Allison 1964). This problem may be overcome by adding the parameter n (the apparent kinetic order) to the equation:

$$pr = \frac{PR_{\max} [I]^n}{K_1 + [I]^n} \quad 5$$

The equation can vary from a hyperbola to a sigmoidal ($n > 1$) curve as n increases above 1. This approach has been utilized in enzyme kinetics and is known as the "Hill equation" (Hill 1913).

The second limitation to equation 5 is that the equation describes a curve which passes through the point (0, 0) of an (X, Y) coordinate system. This does not allow the prediction of responses such as weight loss. Adding the parameter, b , ($b = X$ intercept) removes this restriction.

$$pr = \frac{PR_{\max} [I]^n}{K_1 + [I]^n} + b \quad 6$$

Rearrangement gives:

$$pr = \frac{PR_{\max} [I]^n + bK_1 + bI^n}{K_1 + [I]^n}$$

If we let $(PR_{\max} + b) = R_{\max}$ and simplify pr to r , we have the four-parameter mathematical model for physiological responses:

$$r = \frac{bK_1 + R_{\max} [I]^n}{K_1 + [I]^n} \quad 7$$

This can be more conveniently written:

$$r = \frac{b[K.5]^n + R_{\max} [I]^n}{[K.5]^n + [I]^n} \quad 8$$

where:

r = physiological response

l = nutrient intake or concentration in the diet

b = intercept on the r axis

$R_{\max}$ = maximum response

n = apparent kinetic order

$K0.5$ = intake for $1/2 (R_{\max} - b)$

This model satisfactorily describes all areas of the biological response curve over a wide range of nutrient intakes. The saturation kinetic model by Morgan et al. (1975) has been tested on rats, mice, chicks, swine and man. Many nutrient responses have been studied using this model such as protein, amino acids, selenium, mercury, cadmium, calcium, phosphorus, biotin, pyrodoxe, vitamin B12, vitamin A, vitamin D, thiamin. The type of measured responses utilized in these studies have been: weight gain, serum albumin, hemoglobin, hematocrit, total serum protein, carcass gain of amino acids, tissue enzyme levels, serum B₁₂, folate, tissue cadmium, blood clotting, plasma, vitamin A, tibia femur ash, liver weight, gram protein/total liver weight, mg DNA/g liver, mg DNA/g liver carcass nitrogen, and total food intake (Mercer 1980).

When graded levels (i.e., dietary nutrient concentrations) of an essential nutrient are fed over a range from zero to levels which surpass maximum dietary response levels, a hand drawn response S-shape curve will be observed. The various sections of the curve have been identified by Mercer (1982).

Threshold - the lower range of nutrient concentrations which produce zero or negligible responses by the organism. A positive response ($b > 0$) with zero slope at a low dietary nutrient level implies endogenous stores of that nutrient;

Deficient - the range in which the slope of response increases, but the genetic potential of the animal is not fully expressed;

Adequate - the portion of the curve at which the slope moves from positive towards zero (or a plateau). The genetic potential (assuming no other limiting nutrient) is fully expressed but no "margin of safety" exists for stress, pathology, etc.

Optimal - the range (rather than the point) of maximal response; and

Toxic - the intake level at which the response is diminished.

An excessive dietary level of a nutrient can lead to displacement of other essential nutrients and/or impaired metabolism. For example, when a group of rats were fed an experimental diet with different levels of protein the sigmoidal ($n > 1$) curve was generated based on the four parameters (b , $R_{\max}$, $K_{0.5}$, N). The results were used to predict daily food intake, daily weight gain, and the efficiency of food conversion (daily weight gain/daily food intake) as a function of dietary protein concentration (Mercer et al. 1981). In another study (Mercer et al. 1984), the physiological response (weight gain and food intake) to graded levels of essential amino acids in an experimental diet yielded sigmoidal ($n > 1$) shaped response curves that were analyzed by the four parameter models. These response curves were similar to those seen in the protein concentration studies (Mercer et al. 1981). Gustafson et al. (1984) found that the recommended level of an amino acid mix and/or an individual amino acid for rats by Rogers and Harper (1965) were on the maximum plateau of the curve and were near the point where the curve just approached $R_{\max}$. Thus, the recommended levels appeared to be optimal.

Therefore, the model could be used to determine the nutrient requirements of rats (animals or fish). The model also was used to compare the efficiency of two protein sources (soy vs. casein) (Mercer et al. 1978). The Morgan et al. (1975) model is useful in comparing other nutrients as well. An evaluation of protein quality based on the growth response of rats using the four parameter model was successfully done by Foldin et al. (1977). Following this study, a new protein quality evaluation index was developed by Mercer and Gustafson (1984) called the actual protein utilization (APU). Finally, the model was used to predict the dietary cadmium toxicity utilizing the daily weight gain as an indicator (Gustafson and Mercer 1984).

A recent study by Annett (1985) used the hyperbolic form ($n = 1$) of the model's equation. Annett compared several types of natural food sources for tilapia. However, some of his results showed poor curve fitting values ($r = 0.52$). His values would probably have had a closer fit if he had used the four parameter equation developed by Morgan et al. (1975).

Protein Requirements for Tilapias

Protein requirements for tilapia have been determined based on feeding techniques developed for terrestrial animals. Fish were fed a diet containing graded levels of high quality protein (casein: gelatin = 3:1) over a specific period of time (10 weeks), and the observed protein level providing optimum growth was considered the requirement (Tacon and Cowey 1985).

Protein requirements for tilapia ranged from 25-56 percent crude protein in the diet (Table 1). Fish size, species differences, experimental duration, and feeding rates have probably had a significant impact on optimum protein level for growth. Generally, smaller size fish require higher protein intake than the larger size fish.

Dietary energy and protein requirements for one species of tilapia (T. Zillii) weight 1.5-2 g varied from 3.00-3.74 kcal ME/g feed and 30-40 percent protein (Table 2). This variability is probably due to feeding rates and/or experimental duration. Teshima (1986) reported that feeding rate affects the growth rates of O. niloticus.

Energy Requirements of Tilapias

Fish require less energy for growth than warm blooded animals because fish (ectotherms) 1) do not expend energy to maintain a constant body temperature; 2) bouyancy reduces energy requirement to maintain position in the water, and 3) ammonia is the major protein catabolism end product which is energy efficient (Table 3) when compared to urea or uric acid (Smith 1976).

The optimum ratio of protein to metabolizable energy that produced maximum growth in the channel catfish (Garling and Wilson 1976) was 24 percent protein 2.75 kcal ME/g protein and produced growth similar to diets containing 28 percent protein and 3.41 kcal ME/g protein.

Table 1. Protein requirements (%) for maximum growth of different tilapias of various size groups (from El-Sayed 1987).

Size Group(g)	Species	Protein Requirements (% diet)	Reference
0.3-0.5	<u>S. aureus</u>	36	Davis & Stickney (1978)
0.3-0.8	<u>O. niloticus</u>	35-40	Cruz & Laudencia (1976)
0.56	<u>O. niloticus</u>	35	Teshima et al. (1985)
1.05 1-3	<u>T. zillii</u> <u>O. mossambicus</u>	30-35 29-38	Mazid et al. (1979) Cruz & Laudencia (1976)
1.5-2 3-4	<u>T. zillii</u>	30	El-Sayed (1987)
1.33	<u>T. zillii</u>	32-40	Hauser (1975)
1.37	<u>O. mossambicus</u>	40	Jauncey (1982)
1.45	<u>T. zillii</u>	35-40	Teshima et al. (1985)
2-5	<u>O. mossambicus</u>	30-40	Teshima et al. (1985)
	<u>O. aureus</u>	56	Winfree and Stickney (1981)
3-6	<u>O. niloticus</u>	25-30	Wang et al. (1985)
7.5	<u>O. aureus</u>	35	Winfree and Stickney (1981)
9.0	<u>O. niloticus</u>	35-30	Cruz Laudencia (1976)
6-30	<u>O. mossambicus</u>	30-35	Ross (1982)

Table 2. Dietary energy and protein requirements of *Tilapia zillii* at different feeding rates and experimental durations.

Energy kcal ME/ gradient	Protein %	Feeding rates ¹	Experimental duration (weeks)	Fish size (gram)	References
3.5	35-40	4	4	1.67	Teshima et al. (1978)
3.65	35	10	3	1.80	Mazid et al. (1979)
3.0	30	6	6	1.5	El-Sayed (1987)

¹Feeding rates as a percentage of the fish wet weight.

Table 3. Calculated energy distribution of protein catabolized by ammonotelic, ureotelic, and uricotelic animals (Smith, et al., 1978).

Fraction	Excreted Product		
	Ammonia	Urea	Uric Acid
	kcal/g	kcal/g	kcal/g
Gross energy (GE)	5.70	5.70	5.70
Digestion loss (8%)	0.46	0.46	0.46
Digestible energy (DE)	5.24	5.24	5.24
Metabolic loss	0.72	0.86	1.31
Metabolizable energy (ME)	4.52	4.38	3.93
Heat increment (HI)			
Waste product synthesis	0.00	0.51	0.44
Waste product concentration and excretion	0.00	0.22	0.29
Metabolism of non-nitrogen	0.28	0.28	0.28
Total	0.28	1.01	1.01
Net energy	4.24	3.37	2.92

These two diets produced growth rates higher than a diet containing 36 percent protein and 4.07 kcal ME/g protein. This occurred despite the fact that the three diets contained almost the same ratio of P/ME. A summary of protein to energy ratios requirements for tilapia are provided in Table 4.

Essential Fatty Acids

Barr and Burr (1919, 1930) introduced the concept of the essential fatty acids (EFA) which are necessary for normal physiological functions in animals. Animals (fish) are not able to synthesize W-6 and W-3 essential fatty acids from W-9 non-essential fatty acids (NRC 1983). Stasby (1982) reported that fish oil contain long chain W-3 fatty acids rather than W-6 fatty acids. The major essential fatty acid present in fish is 20:5 W-3 where that of terrestrial animal is 18:2 W-6 (linoleic acid) (Jauncy 1982). Water salinity and temperature probably have an effect on essential fatty acid content in fish; marine fish have higher levels of W-6 fatty acids than freshwater fish and both fishes have higher levels of W-3 fatty acids than W-6 (Halver 1980). W-6/W-3 ratio was found to decrease with increasing water temperature (Halver 1980). Some fish, however, are able to synthesize 18:W-3 and 18:W-6 fatty acids (Cowey and Sargent 1979). The essential fatty acid requirements of Tilapia Zillii was one percent of the diet of 18:2W-6 or 20:4W-6 (Kanazama et al. 1980).

Table 4. Dietary protein and protein to energy ratios requirements for different species of tilapias modified (El-Sayed 1987).

Species	Crude Protein Cp%	Cp/ME Ratio	References
<u>T. zillii</u>	35	100-114 mg Cp/kcal ME	Teshimer et al. (1978)
	35	95 mg Cp/kcal ME	Mazid et al. (1979)
	30	81 mg Cp/kcal ME	Mazid et al. (1979)
	35	100 mg Cp/kcal ME	El-Sayed (1987)
<u>O. aureus</u>	36	123 mg Cp/kcal DE	Winfree & Stickney (1981)
	35	108 mg Cp/kcal DE	Winfree & Stickney (1981)
<u>O. mossambicus</u>	40.5	116.6 mg Cp/kcal ME	Jauncey (1982)
<u>O. niloticus</u>	35	90 mg Cp/kcal DE	Teshima et al. (1985)
	25	71 mg Cp/kcal DE	Wang et al. (1985)

Dietary Carbohydrate

Dietary carbohydrate in fish is used as an immediate source of dietary energy (Phillips et al, 1966, 1967; Buhler and Halver 1961). It could be stored in the fish body as glycogen for short-term energy use (Wendt 1964) or as fat for long-term reserve. It serves as a precursor for many metabolic intermediates such as dispensable amino acids and nucleic acids (NRC 1983). Carbohydrates are absorbed as simple sugars. All glycolytic enzymes for glycolysis, tricarboxylic acid cycle, pentose phosphate shunt, gluconeogenesis and glycogen synthesis have been demonstrated in fish (NRC 1983). Depending on dietary CHO complexity their utilization appears to differ. Channel catfish utilizes polysaccharides for growth more readily than disaccharids or simple sugar (Depree 1966). The shrimp Penaeus japonicus, utilizes maltose or polysaccharides better than monosaccharides (glucose) (Abdel-Rahman et al. 1979). Some fish utilize higher dietary carbohydrate levels than others. Channel catfish (Garling and Wilson 1976, 1977; Likimani and Wilson 1982), common carp (Ogino et al. 1976; Shimeno et al. 1977, 1981; Sen et al. 1978) and red sea bream (Furuichi and Yone 1980) utilize higher levels of carbohydrates than yellow tail (Furuichi and Yone 1980) and salmon (Phillips and Brockway 1956). Low feed conversion were found in common carp, red sea bream, and yellow tail fed diets containing over 40 percent, 30 percent and 20 percent dextrin, respectively (Furuichi and Yone 1980). Garling and Wilson (1977) showed that a diet containing zero carbohydrate levels produced poorer growth in fish

than diets containing carbohydrate to lipid ratio between 45 to 4.5. They concluded that digestible carbohydrates can be utilized effectively by channel catfish and can be substituted for lipids in semipurified diets at a rate of 2.25:1 (commensurate with physiological fuel values) within the above range. The growth of O. niloticus were improved with increasing carbohydrate levels from 0.00 to 40 percent (Anderson et al 1984).

Minerals

Investigations concerning mineral nutrition of O. niloticus have been rather limited. Dietary calcium, phosphorus, zinc and magnesium were extensively investigated.

Dietary calcium is required for the formation of bone, scales, and skin. Tilapia scales contain 19-24 percent of the total body calcium. This level decreases during starvation and/or spawning periods (Garrod and Newell 1958). Trout skin contains 40 percent of the total body calcium (Podoliak and Holden 1965; Simikiss 1974). Fish are able to absorb calcium from feeds via their intestinal tract and from water through the gills. Studies on the availability and absorption of dietary calcium by fish are limited (NRC 1983). Dietary calcium availability is dependent on the chemical form of dietary calcium. Tricalcium phosphate is the least available form of calcium. Dicalcium phosphate is moderately available. Monocalcium phosphate is the most readily available form of dietary calcium. Calcium absorption in turn, depends on the availability of dietary vitamin D (ergocalciferol and/or cholecalciferol). Vitamin D serves as

a precursor to 1, 25-dihydroxycalciferol which stimulates calcium absorption. Calcium is essential for blood clotting, nerve impulse transmission, osmoregulation and enzymes cofactor.

Dietary phosphorus is required along with calcium for the formation of skeletal muscle. The ratio of calcium and phosphorus in bone ranges from about 1.5-2.1 for tilapia (Ogino et al. 1979). The whole body calcium and phosphorus ratio of various fishes ranges from 0.7 to 1.6 (Arai et al. 1975; Watanabe et al. 1980,b). The total body phosphorus is about 0.4-0.5 percent of fresh weight (Ogino and Takeda 1976). Phosphorus is essential for many metabolic processes. It is part of adenosine triphosphate, phospholipids, deoxyribonucleic acid (DNA), ribonucleic acid (RNA) and various coenzymes. It is involved in energy transformation, cellular membrane permeability, genetic coding, and general control of reproduction and growth. It serves as a pH buffer in body fluid and cells (Wasserman 1960). The minimum dietary phosphorus requirement for O. niloticus is 0.9 (Watanabe et al 1980b). Zinc is essential for the function of many enzymes. In severe zinc deficiencies the activities of alkline phosphatase (Kirchgessner et al. 1976), liver (Kfoury 1967), retina (Huber and Gershoff 1975), and liver nuclear DNA dependent RHA-polymerase may be depressed. Dietary zinc has been quantitated for rainbow trout (Ogino and Yang 1978); and the carp (Cyprinus carpio) (Gatlin et al. 1983). Common deficiency symptoms are associated with a lack of zinc in rainbow trout, carp (Ogino and Yang 1978, 1979), and channel catfish (Gatlin et al. 1983). Observed symptoms are growth retardation and a high incidence of cataracts. Several factors affect the requirement

of zinc such as calcium level (Forbes 1960), phytic acids (Oberleas 1962) and the source of protein (Ziegler et al. 1961; Smith et al. 1962). Dietary zinc levels up to several hundred do not appear to be injurious to rainbow trout (Ogino and Yang 1979). Zinc requirements range from 15-30 mg Zn/kg diet for carp and rainbow trout (Gatlin et al. 1983 and Ogino and Lang 1978). These values are similar to those required for chickens (Roberson and Schaible, 1958 and Ziegler et al. 1961); rats (Forbes and Yohe 1960); piglets (Shanklin et al 1968), Japanese quail (Fox and Jacobs 1967) and channel catfish (Gatlin et al 1983). O. niloticus zinc requirements probably fall within the same range.

Magnesium plays an important role as an essential ion in many fundamental enzymatic reactions. These enzymes include: 1) transfer phosphate groups (phosphokinases), hence magnesium is involved in phosphorylation of glucose in its anaerobic metabolism and oxidative decarboxylation in the citric acid cycle requiring thiamin pyrophosphate; 2) acylate coenzyme A in the initiation of fatty acid oxidation (thiokinases); 3) hydrolyze phosphate and phosphate groups (phosphatases and pyrophosphatases) for which magnesium is activator; 4) activate amino acids (amino acid acyl synthesis through its action on ribosomal aggregation (Shilis 1984). Deficiency causes poor growth, anorexia, sluggishness, muscle flaccidity, high mortality, and suppresses magnesium levels in the whole body, and bones (NRC 1983). The minimum dietary requirement for channel catfish is 40 mg/kg when reared in water containing 1.6 ppm magnesium (Gatlin 1984).

CHAPTER III

MATERIALS AND METHODS

O. niloticus fingerlings were fed ten graduated levels of each of six practical feeds. Three replicates per feed were fed for five weeks. Feeding levels were based on percentage of the fish wet body weight adjusted weekly. At the beginning and end of the five-week period, the fish were weighed, sacrificed, ground and stored frozen for chemical analyses. Proximate analysis and mineral analyses (Ca, P, Zn, and Mg) were performed on the experimental diets and fish body samples. The results of the dietary intake and the fish responses were analyzed by the four parameters of the saturation kinetic model for dietary evaluation.

Cultural Conditions

All experiments were conducted in the MSU Aquaculture Lab in 45 specially constructed ten-gallon glass aquariums. Aluminum screens (0.25 square inch mesh) covered the aquarium bottom to prevent the experimental fish from eating their feces. A flow-through system was built as described by Garling and Wilson (1975). Tanks were cleaned once each week.

Well water was used in this study. The water was aerated to

remove excessive iron by filtration units. A gas water heater was used to raise the water temperature from $11.5 \pm 1^{\circ}\text{C}$ to $24 \pm 1^{\circ}\text{C}$.

Fish

O. niloticus fingerlings (3 ± 1 gram), offspring of O. niloticus obtained from Auburn University in Alabama in 1985, were used as experimental fish. Fish were bred in tanks under controlled conditions. Ten fish were stocked in each tank and were randomly assigned a feeding level. Each tank was considered as an experimental unit. Fish were weighed weekly to adjust feeding levels. At the end of each diet experiment, fish from each tank were weighed, sacrificed, and blended using a commercial blender. The ground fish were frozen at -7.8°C for subsequent body composition analysis.

Fish Feeds

Five practical tilapia feeds from the developing countries of Honduras, Indonesia, Panama, Thailand, and Egypt were tested. The diets from Honduras, Indonesia, Panama and Thailand were sent to Michigan State University by USAID Title XII CRSP, Pond Dynamics/Aquaculture. The Egyptian practical tilapia feed was provided by the Egyptian Ministry of Agriculture. A sample of 10 kilograms of the American tilapia feed was obtained from a commercial tilapia farm, Fish Breeders of Idaho. This feed was manufactured by Farmers Union Control Exchange, Incorporated of St. Paul, Minnesota. Since all diets were closed-formula feed, dietary ingredient lists were not available.

All feeds were originally processed as sinking pellets except the feed from Thailand which was an extruded floating pellet. In order to produce feeds of equal and appropriate pellet size, each feed was blended in a Waring commercial blender. Feeds were then mixed with water (200 ml of 50°C distilled water per 500 g of diet for 20 minutes) using a Univex commercial food mixer. When the diet began to clump, it was passed through a commercial food grinder to form a spaghetti-like extruded diet. The extruded diet was dried at room temperature for 24 hours in a forced air drying oven. The dried spaghetti-like diet was blended for approximately ten seconds in a Waring blender and the resulting pellets passed through standard sieves to separate pellets sizes. The 0.2mm size pellets were used in this study. The dry weight of each diet (constant weight) was determined using a vacuum oven set at 60°C for 24 hours. The results obtained were: 95.61, 90.77, 97.2, 90.14, 92.41, and 92.32 for pellets from Egypt, Honduras, Indonesia, Panama, Thailand and the United States, respectively. All diets were stored frozen for subsequent analysis and feeding trials.

Feeding Trials

Each feed was fed on a dry weight bases to triplicate tanks of fish as a percentage (0, 0.5, 1.0, 1.5, 2, 2.5, 3, 3.5, 5 and 7%) of the total fish wct weight per tank per day. Low levels (0.5, 1 and 1.5%) were fed once a day while higher levels were fed half the total amount twice a day. The daily amount of food was weighed in small

vials every three days and kept under refrigeration until fed. A period of five weeks was required to test each experimental diet. However, an additional five weeks were required to test all the experimental feeds together at higher feeding rates to reach the growth plateau response. At the end of each feeding experiment, fish from each tank were weighed, sacrificed, and blended using a commercial blender. The ground fish were frozen at -7.8°C for subsequent body composition analysis.

Chemical Analysis

Samples of each diet and ground fish were analyzed using standard AOAC (1975) methods for: moisture, crude proteins, crude fat, total energy, ash, calcium, phosphorus, zinc and magnesium. Moisture was measured using vacuum ovens at 60°C for 16 hours. Crude protein was measured using macro-Kjeldahl. Total ash was measured using a muffle furnace for 16 hours at 600°C . Crude fat was measured using soxhlet apparatus for 16 hours. Anhydrous ether was used as a crude fat solvent. A Parr 1241 Bomb Calorimeter was used to determine the gross energy (Lovell, 1975). Calcium, phosphorus, zinc and magnesium were measured using an instrumentation Laboratory AA/EE Spectrophotometer 951.

Mathematical and Statistical Analysis

The four-parameter saturation kinetic model for physiological response (Mercer 1978) was used to analyze the data as the following example:

Nutrient intake ¹ I (unit/gr fish/day)		Nutrient response (unit per day (ro: observed response) (g response/ gfish/day)
Diet #1	0.75	0.031
	1.20	0.095
	1.90	0.176
	2.60	0.230
	3.30	0.241

- (1) Nutrients included: protein, carbohydrates, fat, any mineral (Ca, P, Zn, Mg) or the diet as a whole.

$$r = (bK_I + R_{\max} I^n) / (K_I + I^n) \text{-----1}$$

1. Equation (1) was rearranged to:

$$r = -K_I (r/I^n) + bK_I (1/I^n) + R_{\max}$$

Then the multiple linear regression program was applied to determine the three independent variables at a given (n).

2. The theoretical values of (r) were calculated at the specific n.
(theoretical response)

$$r_{jt} = -K_I (r_o/I^n) + bK_I (1/I^n) + R_{\max}$$

3. The sum of squares of errors between the observed and the theoretical response (rt, ro) were calculated.

$$(\text{residual sum of squares}) \text{RSS} = \sum_{j=0}^N (r_j (\text{observed}) - r_j$$

(theoretical)).

4. Steps 1-3 were repeated using different values of N until the minimum value of RSS was obtained.
5. The four independent parameters of the nutrient response was used to plot the predictive curve.
6. The nutrient intake at half-maximal response ($K_{0.5}$) was calculated from the equation:

$$K_{0.5} = (K_i)^{1/n}$$

7. Depending on the four independent parameters and the specific curve for each nutrient, each diet was compared.
8. The dietary nutrient intake required for the maintenance of the original weight (the dietary response is equal to zero). $I_r=0$ was calculated from the general equation.
9. An efficiency parameter was developed by Mercer (1982) that measures the greatest response with the smallest intake value. By calculating the intake at maximum response from this equation:

$$I_{emx} = K_{0.5} (n-1)^{1/n}$$

The response at I_{me} was calculating from the general equation. The maximum efficiency was calculated as

$$E_{mx} = \frac{R_{emx} - b}{I_{emx}} .$$

10. Another efficiency parameter was used in this study in the dietary efficiency at half maximal response $E_{mx.5}$.

11. The confidence limits for each parameter were estimated using the Analysis of Variance for Multiple Regression Techniques (Draper 1966).

CHAPTER IV

RESULTS

The groups of fish fed the tilapia feed from Egypt experienced high mortalities due to a bacterial infectious disease in their diet. The presence of the bacteria in the feed was confirmed by the Michigan State University Small Animal Diagnostic Lab. Since a sufficient quantity of the Egyptian feed was not available after initial testing, it was excluded from further study.

Dietary and nutrient response curves for O. niloticus fed diets from five countries are shown in this section. The purpose of these curves is to demonstrate the characteristics of diet on nutrient-response relationship. The four parameters ($R_{\max}$, $K_{0.5}$, n , and b) and the shape of the curves vary for each diet or nutrient-response relationship indicating differences between the tested diets or their dietary nutrients. Each dietary or nutrient intake (various amounts of feed or nutrients fed throughout the five-week experimental period) observed response (determined weight gain or net nutrient deposition), and calculated response (rc) from the four parameters equation using the actual dietary (or nutrients intake values, (I) and the calculated four parameters ($R_{\max}$, $K_{0.5}$, n , and b) are summarized in separate tables.

Each point (X) on the curves represents the mean of three observations. The confidence limits of the four parameters is 95 percent. Each observation represents a steady-state equilibrium. This was achieved by the fish based on the limiting nutrients represented by intake level (I). All points above the I axis are in positive balance with the environment. All points below the I axis are in negative balance (Draper et al. 1966). As the responses approach R_{max} the condition of the nutrient causing that response becomes less limiting. This will continue until any limitation on the response passes to some non-nutritional source such as the fish's genetic potential.

Dietary Analysis

The proximate analysis of the five O. niloticus diets showed similarities and differences between their dietary nutrients (Table 5). Crude protein content of the diets ranged from 17.29 in the Thailand diet (TD) to 32.29 in the Indonesian diet (ID). The crude protein content of TD was very low when compared to the dietary requirements of tilapia fingerlings (3-6g) which are 25-30 percent protein (Wang et al. 1985). ID had higher crude protein level than the the dietary requirements. The Honduran (HD), Panamanian diet (PD), and the American diet (AD) were found to contain similar crude protein levels of 24.63, 25.24, and 24.53 percent, respectively, which are similar to the dietary requirements of O. niloticus (3-5 g).

Table 5. Proximate analysis of the five practical tilapia diets (AOAC 1980).

Dietary Source	Honduras	Thailand	Panama	Indonesia	USA
Dry matter %	90.77	92.41	90.14	97.22	92.32
Crude protein %	24.63	17.29	25.24	32.68	24.53
Crude fat %	6.40	9.46	5.16	8.33	11.39
Crude fiber %	10.33	13.01	5.87	8.38	12.29
Ash %	8.97	10.34	14.74	12.41	8.70
CHO %	40.44	42.313	39.13	42.31	35.41
Gross energy kcal/g diet	4.18	4.14	3.93	4.33	4.71
Metabolizable energy* kcal/g	4.18	3.24	3.44	3.47	3.38
Crude protein mg/energy kcal	77.00	53.00	73.10	94.00	73.00

*Calculated value based on the physiological fuel values.

Metabolizable energy values (ME) of all test diets were calculated based on the physiological fuel value of carbohydrate, protein and lipids of 4, 4, and 9 kcal/g, respectively. ME ranged between 3.2 to 3.5 (Table 5). The test diets, therefore, were not isocaloric diets. The ID, PD diets were isocaloric. They contained the highest ME values of any of the diets tested. The AD had a slightly lower ME value than the ID and PD. The TD had had a lower ME value than the AD. The HD had the lowest ME value of all diets (see Table 5). Metabolizable energy value of all diets fell within the dietary requirements of tilapia (Jauncey et al. 1982). Crude protein to energy ratios (mg crude protein/kcal ME or Cp/ME) were found to be similar in AD, PD and HD. The ID had a higher Cp/ME ratio, while the TD contained the smallest Cp/ME.

The experimental diets ranged from 5.2 to 11.4 of crude fat content (10 percent crude fat is the recommended dietary level for tilapia (Jauncy and Ross 1982). The AD had the highest crude fat content of all diets and was slightly higher than the recommended level. The TD contained similar crude fat levels to the recommended levels.

Growth

The effect of the five practical tilapia diets from Honduras, Thailand, Panama, Indonesia, and the U.S. on the growth of O. niloticus fingerlings is shown in Table 6, 7, 8, 9 and 10 and graphically in Figures 2, 3, 4, 5, and 6. The parameters of the

Table 6. Total food intake, weight gain (ro), and the theoretical response (rc) of O. niloticus fed varying percentages of the Honduran tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.1400	-0.1184
0.5	0.1690	-0.0141	-0.0417
1.0	0.3570	0.1230	0.9420
1.5	0.5530	0.1930	0.2215
2.0	0.7490	0.2370	0.3190
2.5	0.8890	0.4110	0.3724
3.0	1.2060	0.4860	0.4576
3.5	1.4150	0.5300	0.4954
5.0	2.1150	0.5700	0.5677
7.0	3.3800	0.5890	0.6174

¹Daily food intake as a percentage of the wet body weight.

²Total intake (mg/g fish/five weeks).

³Total weight gain deposition per gram of fish wet weight during the five-week period.

⁴Calculated weight gain from the saturation kinetic equation (Morgan et al. 1975).

Table 7. Total food intake, weight gain (ro), and the theoretical response (rc) of *O. niloticus* fed varying percentages of the Thailand tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	0.1568	-0.15
0.5	0.1790	0.0076	0.01
1.0	0.3750	0.0890	0.11
1.5	0.5600	0.1809	0.19
2.0	0.6580	0.2536	0.23
2.5	0.9650	0.3000	0.30
3.0	1.1710	0.3375	0.34
3.5	1.4350	0.3910	0.38
5.0	2.0150	0.4230	0.43
7.0	2.7890	0.4800	0.48

¹Daily food intake as a percentage of the wet body weight.

²Total intake (mg/g fish/five weeks).

³Total weight gain deposition per gram of fish wet weight during the five-week period.

⁴Calculated weight gain from the saturation kinetic equation (Morgan et al. 1975).

Table 8. Total food intake, weight gain (ro), and the theoretical response (rc) of *O. niloticus* fed varying percentages of the Panamanian tilapia feed.

$\% \text{ BW}^1$	Intake ²	ro ³	rc ⁴
0	0.0000	-0.1400	-0.13
0.5	0.1810	0.0520	0.03
1.0	0.3870	0.1990	0.20
1.5	0.5730	0.2670	0.30
2.0	0.7910	0.3750	0.39
2.5	1.0340	0.4690	0.46
3.0	1.1610	0.4970	0.49
3.5	1.5080	0.6000	0.54
5.0	2.1400	0.5970	0.60
7.0	3.4700	0.6290	0.65

¹Daily food intake as a percentage of the wet body weight.

²Total intake (mg/g fish/five weeks).

³Total weight gain deposition per gram of fish wet weight during the five-week period.

⁴Calculated weight gain from the saturation kinetic equation (Morgan et al. 1975).

Table 9. Total food intake, weight gain (ro), and the theoretical response (rc) of *O. niloticus* fed varying percentages of the Indonesian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.1400	-.011
0.5	0.1790	0.0580	0.00
1.0	0.3840	0.2010	0.21
1.5	0.6090	0.3480	0.41
2.0	0.8620	0.5930	0.56
2.5	1.0810	0.6510	0.65
3.0	0.3040	0.6880	0.72
3.5	1.6170	0.8430	0.78
5.0	2.1310	0.8590	0.84
7.	2.9360	0.8270	0.88

¹Daily food intake as a percentage of the wet body weight.

²Total intake (mg/g fish/five weeks).

³Total weight gain deposition per gram of fish wet weight during the five-week period.

⁴Calculated weight gain from the saturation kinetic equation (Morgan et al. 1975).

Table 10. Total food intake, weight gain (ro), and the theoretical response (rc) of O. niloticus fed varying percentages of the U.S. tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.1400	-.012
0.5	0.1660	-0.0670	-0.09
1.0	0.3530	0.0040	-0.01
1.5	0.5310	0.0710	0.07
2.0	0.7240	0.1330	0.15
2.5	0.9350	0.2120	0.23
3.0	1.1450	0.2840	0.29
3.5	1.3440	0.3640	0.33
5.0	2.1020	0.4530	0.43
7.0	2.9980	0.4560	0.48

¹Daily food intake as a percentage of the wet body weight.

²Total intake (mg/g fish/five weeks).

³Total weight gain deposition per gram of fish wet weight during the five-week period.

⁴Calculated weight gain from the saturation kinetic equation (Morgan et al. 1975).

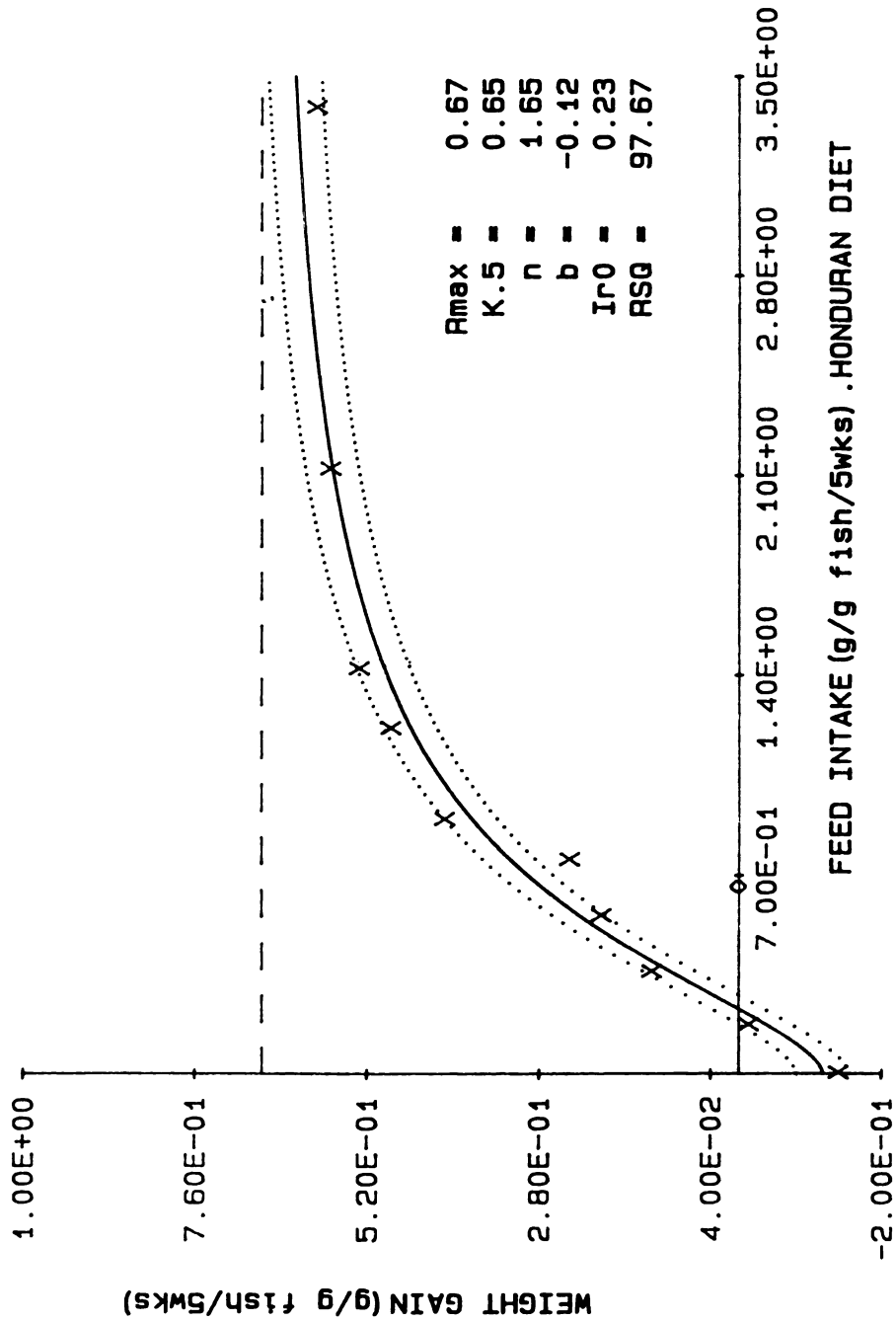


Figure 2. Theoretical nutrient response curve of feed intake vs weight gain deposition of *Q. niloticus* fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group means, $n=3$).

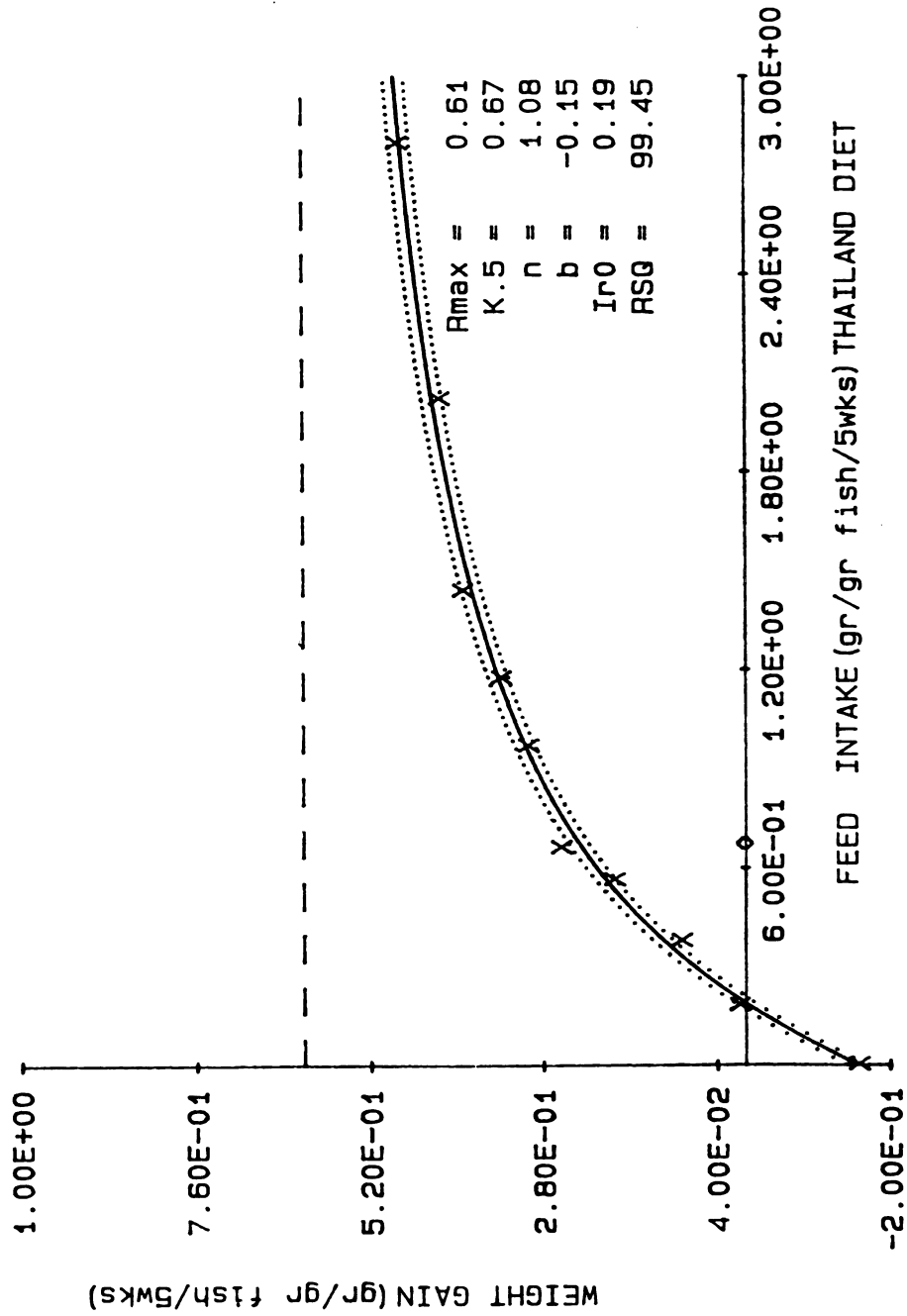


Figure 3. Theoretical nutrient response curve of feed intake vs weight gain deposition of *O. niloticus* fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group means, $n=3$).

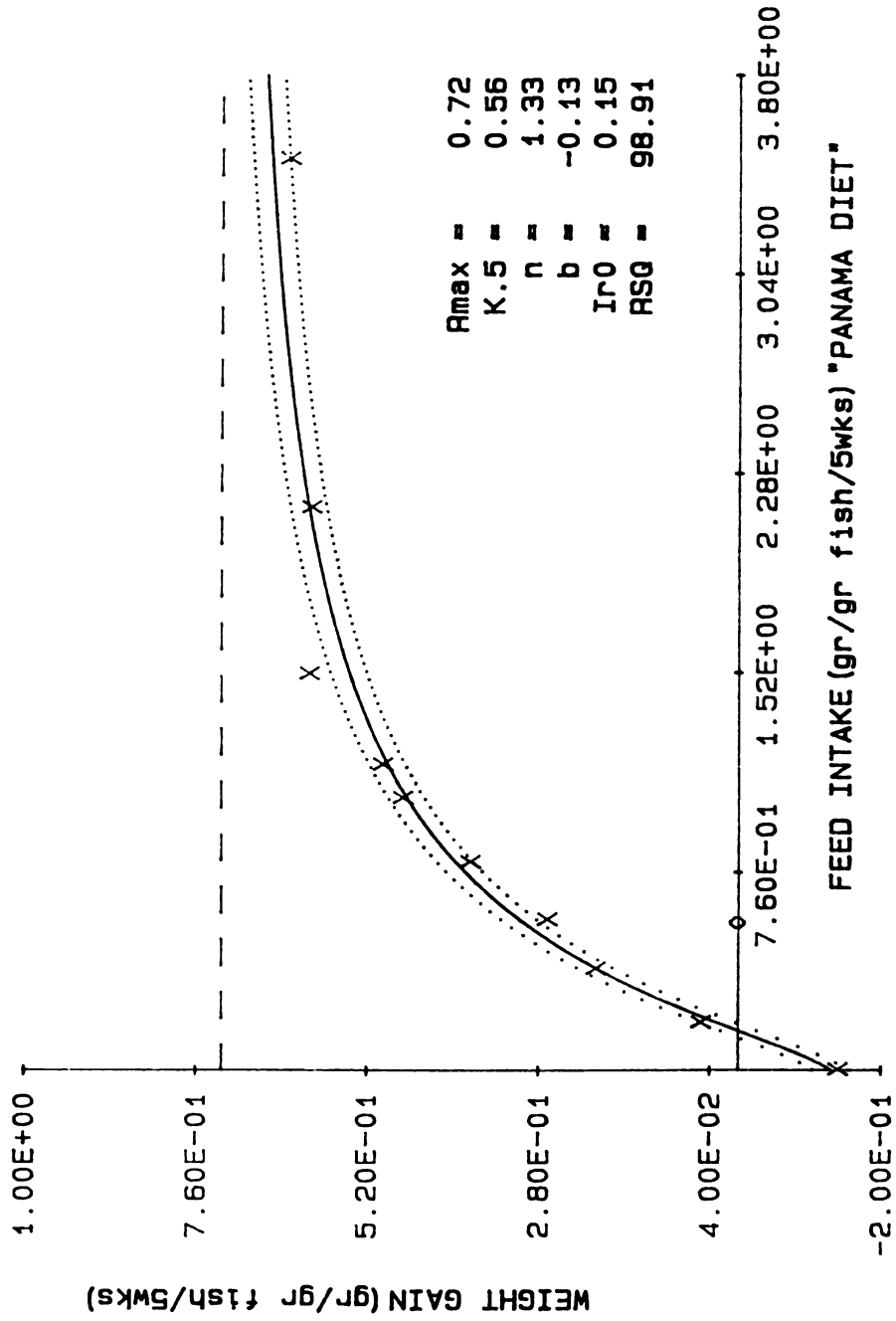


Figure 4. Theoretical nutrient response curve of feed intake vs weight gain deposition of *O. niloticus* fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

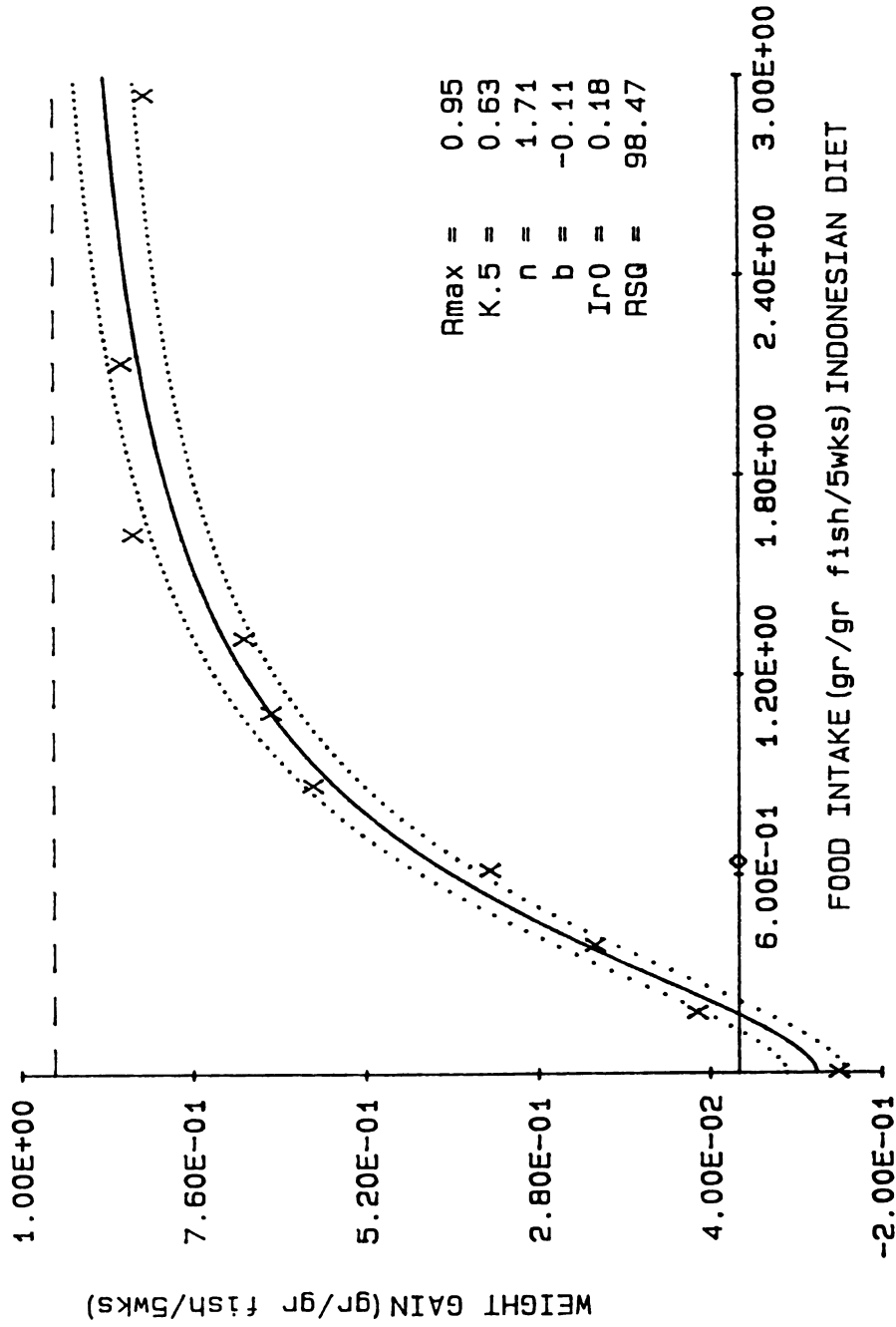


Figure 6. Theoretical nutrient response curve of feed intake vs weight gain deposition of *O. niloticus* fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group means, $n=3$).

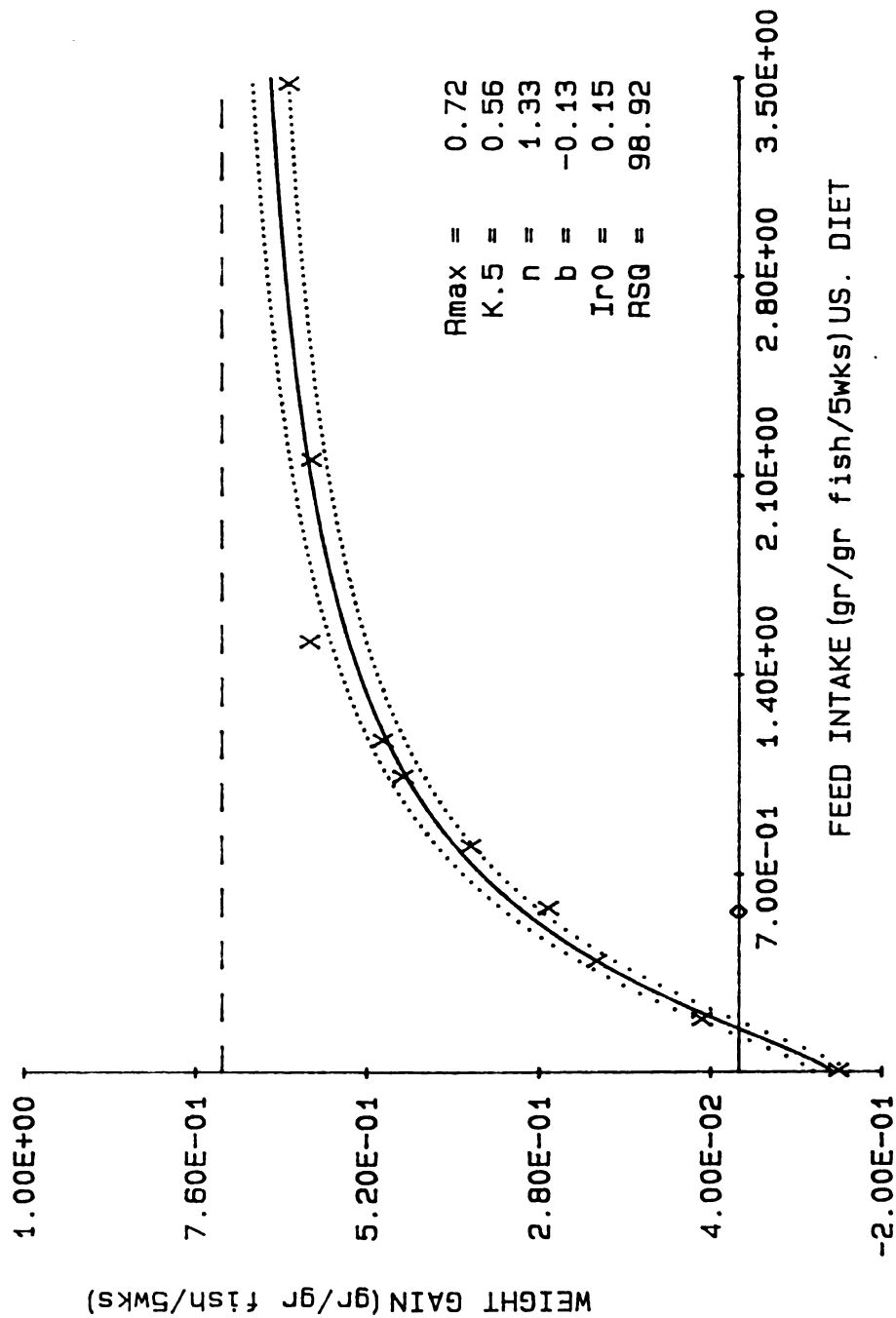


Figure 5. Theoretical nutrient response curve of feed intake vs weight gain deposition of *O. niloticus* fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group means, $n=3$).

Table 11. Parameters derived from fitting food intake and weight gain/g of fish/five-week period as a function of food intake level as a percentage of fish body weight.

Source of Diet	$R_{\max}^1$	$K0.5^2$	b^3	a^4	$I_{r=0}^5$	$\% BW^6$	I_{enr}^7	$\% BW^8$	R_{enr}^8	R_9	$R_{\text{mx}.5}^{10}$
HONDURAS	ab 0.67 ± 0.08	a 0.65 ± 0.11	-0.12 ± 0.04	1.65 ± 0.34	0.24 ± 0.03	0.59	0.23	1.14	0.16	0.64	0.61
THAILAND	ab 0.61 ± 0.07	a 0.67 ± 0.15	-0.15 ± 0.14	1.25 ± 0.47	0.19	0.52	0.068	0.19	-0.095	0.87	0.59
PANAMA	b 0.72 ± 0.06	a 0.56 ± 0.08	-0.13 ± 0.03	1.28 ± 0.4	0.15	0.41	0.24	0.50	-0.084	0.87	0.73
INDONESIA	c 0.95 ± 0.09	a 0.63 ± 0.08	-0.11 ± 0.06	1.71 ± 0.36	0.18	0.52	0.515	1.29	0.33	0.85	0.84
U.S.A.	a 0.55 ± 0.06	b 0.89 ± 0.10	-0.12 ± 0.02	1.78 ± 0.31	0.38	1.07	0.77	2.05	0.17	0.38	0.37

¹ $R_{\max}$: The maximum theoretical response.

² $K0.5$: The intake level at half maximum response.

³ b : The response at zero intake level.

⁴ a : The kinetic order.

⁵ $I_{r=0}$: The food intake at zero response (maintenance).

⁶ $\% BW$: Daily food intake as a percentage of body weight for the previous column.

⁷ I_{enr} : The intake at maximum efficiency.

⁸ R_{enr} : The response at maximum efficiency.

⁹ R_9 : Maximum efficiency.

¹⁰ $R_{\text{mx}.5}$: Overall efficiency.

growth model and their derivatives $I_r=0$, $E_{\max}$, $E_{\max.5}$ which describe the weight gain for each diet as shown in Table 11.

$R_{\max}$: shows the maximum theoretical growth response of tilapia for each diet (the genetic potential of the fish towards a specific diet or nutrient. Fish fed the ID had a significant by higher $R_{\max}$ than fish fed all other tested diets. The $R_{\max}$ value for fish fed the PD and AD were not significantly different from that of HD or TD. Fish fed the PD on the other hand had a significantly higher $R_{\max}$ value than that of AD.

$K_{0.5}$: The amount of feed intake that produced half maximum growth response (mg/g fish/five weeks) was highest (poor quality diet) for tilapia fed the TD and AD. The $K_{0.5}$ values for fish fed HD, PD, ID were not significantly different from each other, and lower than that of the TD and AD.

n : the kinetic order resulted in a sigmoidal ($n>1$) shaped curve in all growth results.

b : the dietary response at zero food intake level (control group were not significantly different, as expected).

The dietary maintenance intake level (zero weight gain, ($I_r=0$) showed that fish fed the PD had the lowest $I_r=0$ value (best value) followed by the fish fed HD, ID, TD and AD, respectively. The maximum dietary growth efficiency (ME) which measures the greatest growth response with the smallest intake value was highest of fish fed PD,

TD, and ID, followed by fish fed the HD and AD. The overall dietary growth efficiency value (the efficiency at the $K_{0.5}$ $E_{mx.5}$ showed a sharp decrease from ME value in fish fed the TD when compared to fish fed all other test diets. The overall growth efficiency was the best in fish fed the ID then PD, HD, TD, and AD, respectively.

Net Energy Deposition

The dietary energy intake and the deposited energy in the fish bodies (kcal/gr fish initial weight/five weeks) estimated and calculated in Tables 12, 13, 14, 15 and 16. They are graphically represented in Figures 7, 8, 9, 10 and 11. The parameters of the four parameter model and their derivatives that were achieved by the fish are shown in Table 17.

R_{max} : The maximum theoretical energy deposition value in the fish fed TD was lower than that of PD. However, R_{max} value for fish fed the TD and PD were not significantly different from fish fed any of the three other diets.

$K_{0.5}$: Dietary energy intake that deposit half maximum energy deposition ($1/2 R_{max}$) in the fish varied between diets. The fish fed the ID and the lowest $K_{0.5}$ value of all diets and was not significantly different from those fed PD or ID. Fish fed ID, TD, and PD had lower $K_{0.5}$ values than those fed the AD. Fish fed the HD were not significantly different from the ones fed the TD nor AD in terms of the $K_{0.5}$ value.

Table 12. Gross energy intake, observed deposition (ro), and calculated deposition (rc) of O. niloticus fed varying percentages of the Honduran tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.1570	-0.09
0.5	0.1890	-0.0180	-0.08
1.0	1.6800	0.1570	0.13
1.5	2.5870	0.2200	0.28
2.0	3.5270	0.3310	0.41
2.5	4.1490	0.5960	0.48
3.0	5.6300	0.6280	0.63
3.5	6.6080	0.7140	0.70
5.0	11.0890	0.8350	0.89
7.0	16.8100	1.0210	0.99

¹Daily food intake as a percentage of the wet body weight.

²Total energy intake (kcal/g fish/five weeks).

³Total energy deposition per gram of fish wet weight during the five-week period.

⁴Calculated energy deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 13. Gross energy intake, observed deposition (ro), and calculated deposition (rc) of O. niloticus fed varying percentages of the Thailand tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.2100	-0.17
0.5	0.7400	0.0110	-0.06
1.0	1.5540	0.1350	0.13
1.5	2.3200	0.2600	0.29
2.0	3.1290	0.3920	0.44
2.5	3.9950	0.5260	0.55
3.0	5.1839	0.83250	0.67
3.5	5.9420	0.8250	0.72
5.0	8.3710	0.8500	0.83
7.0	11.5450	0.8390	0.90

¹Daily food intake as a percentage of the wet body weight.

²Total energy intake (kcal/g fish/five weeks).

³Total energy deposition per gram of fish wet weight during the five-week period.

⁴Calculated energy deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 14. Gross energy intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Panamanian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.2090	-0.20
0.5	0.7100	0.0740	0.05
1.0	1.4900	0.3030	0.28
1.5	2.2600	0.4200	0.46
2.0	3.1200	0.5370	0.60
2.5	4.0700	0.7400	0.72
3.0	4.5800	0.7980	0.77
3.5	5.9400	0.9000	0.87
5.0	8.4400	0.9890	0.99
7.0	12.3500	1.0690	1.09

¹Daily food intake as a percentage of the wet body weight.

²Total energy intake (kcal/g fish/five weeks).

³Total energy deposition per gram of fish wet weight during the five-week period.

⁴Calculated energy deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 15. Gross energy intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Indonesian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.1770	-0.14
0.5	0.8030	0.1110	0.04
1.0	1.6630	0.3030	0.34
1.5	2.6360	0.5490	0.61
2.0	3.7320	0.8780	0.81
2.5	4.6810	0.9150	0.91
3.0	5.6480	0.9550	0.98
3.5	7.0030	0.1060	1.04
5.0	9.2290	1.0930	1.10
7.0	12.7130	1.1040	1.15

¹Daily food intake as a percentage of the wet body weight.

²Total energy intake (kcal/g fish/five weeks).

³Total energy deposition per gram of fish wet weight during the five-week period.

⁴Calculated energy deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 16. Gross energy intake, observed deposition (ro), and calculated deposition (rc) of O. niloticus fed varying percentages of the U.S. tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.1740	-0.19
0.5	0.8900	-0.0920	-0.07
1.0	1.8980	0.0510	0.08
1.5	2.8550	0.2300	0.20
2.0	3.8900	0.3940	0.32
2.5	5.3800	0.4000	0.44
3.0	6.1760	0.4550	0.50
3.5	7.6240	0.5980	0.59
5.0	11.4700	0.7380	0.74
7.0	15.9010	0.8500	0.84

¹Daily food intake as a percentage of the wet body weight.

²Total energy intake (kcal/g fish/five weeks).

³Total energy deposition per gram of fish wet weight during the five-week period.

⁴Calculated energy deposition from the saturation kinetic equation (Morgan et al. 1975).

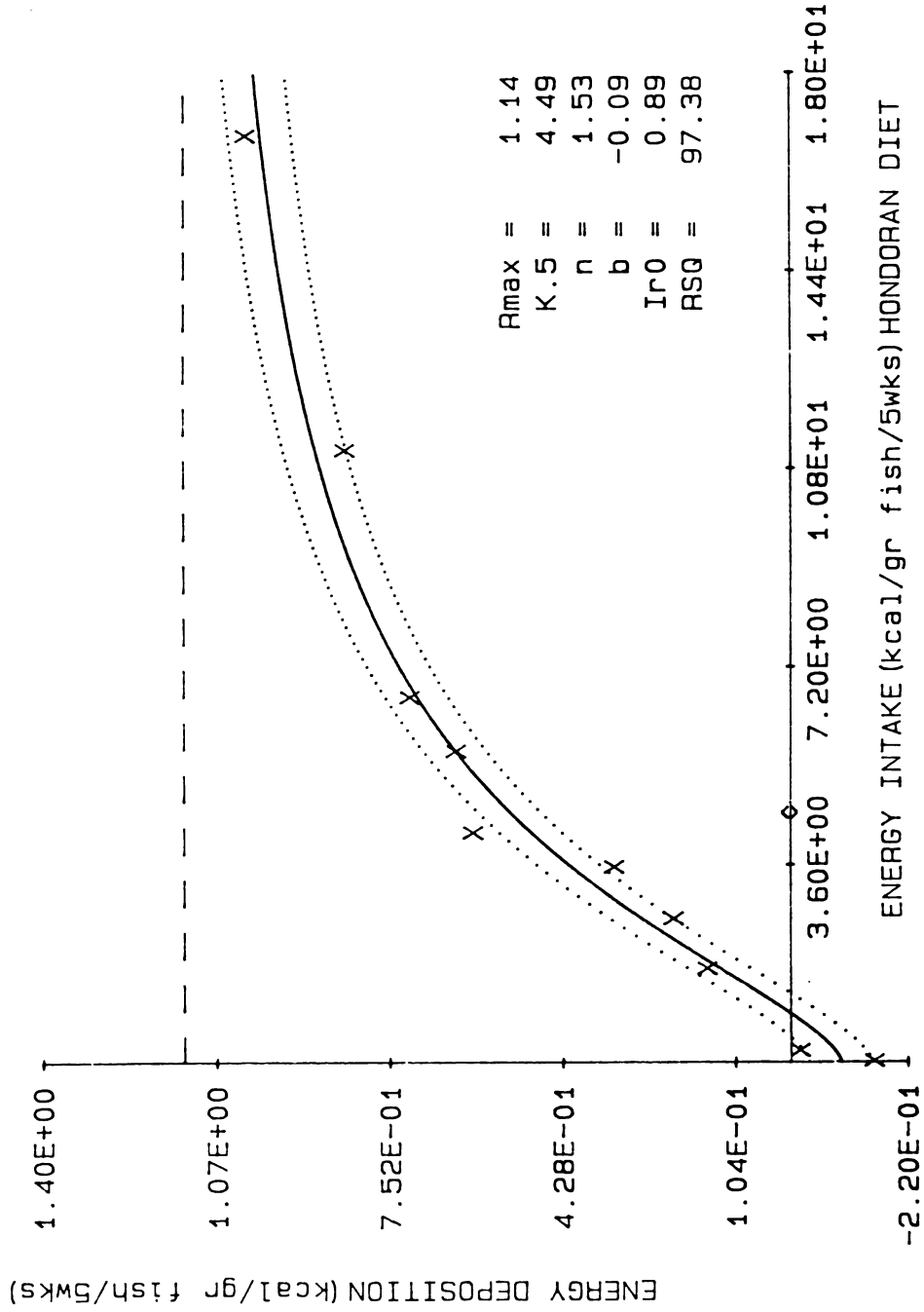


Figure 7. Theoretical nutrient response curve of gross energy intake vs gross fat energy deposition of *Q. niloticus* fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

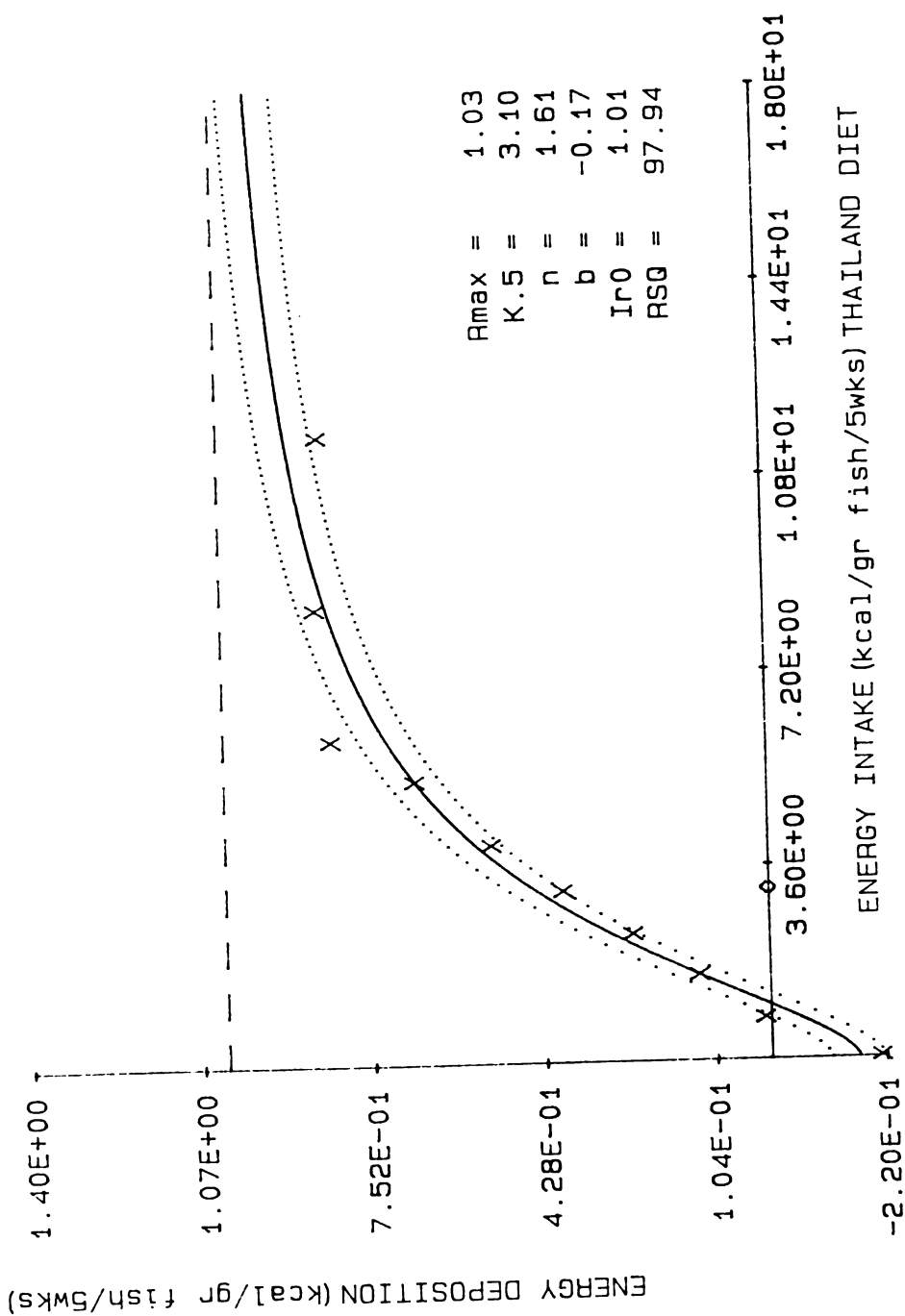


Figure 8. Theoretical nutrient response curve of gross energy intake vs gross fat energy deposition of *O. niloticus* fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

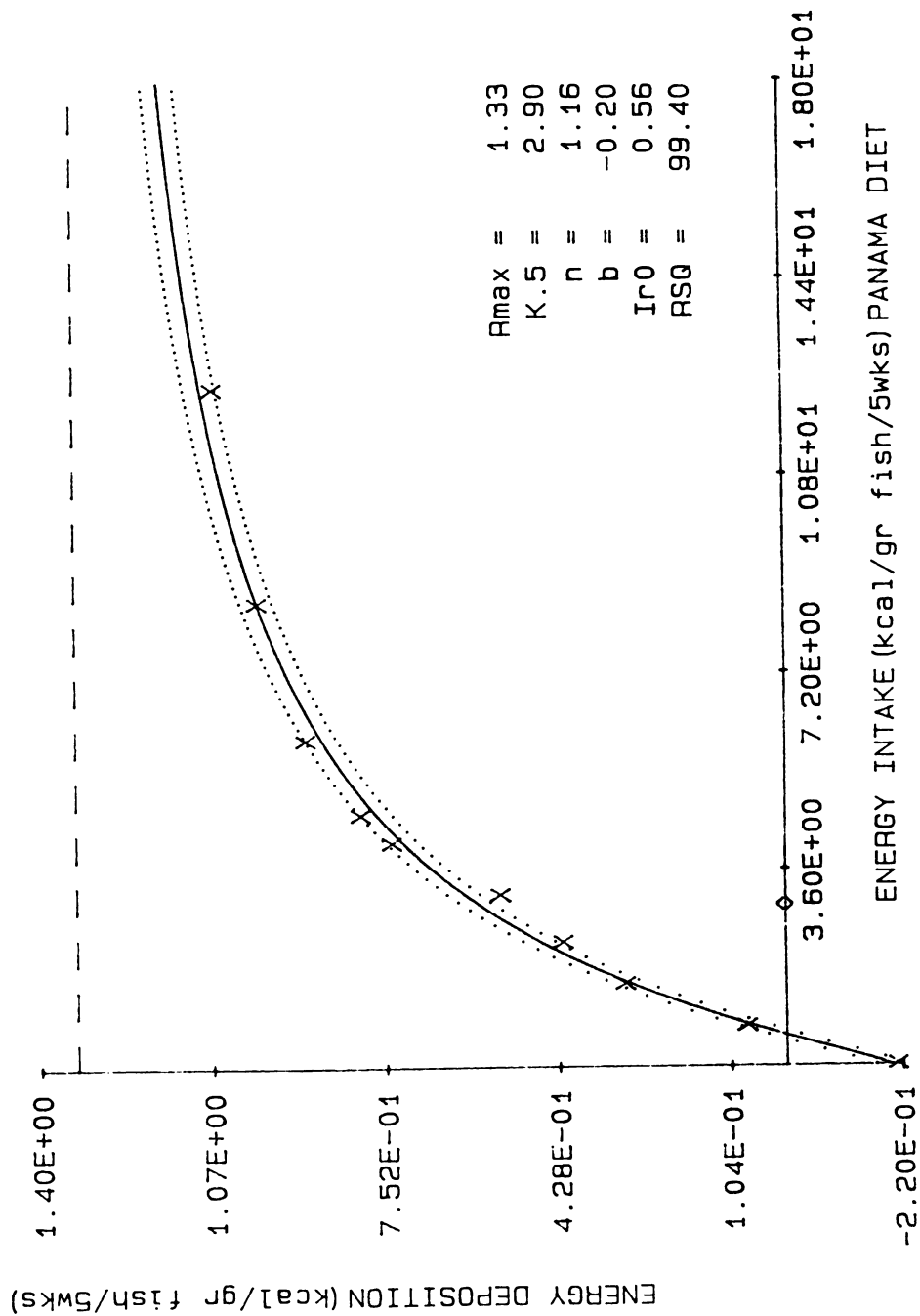


Figure 9. Theoretical nutrient response curve of gross energy intake vs gross fat energy deposition of *O. niloticus* fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

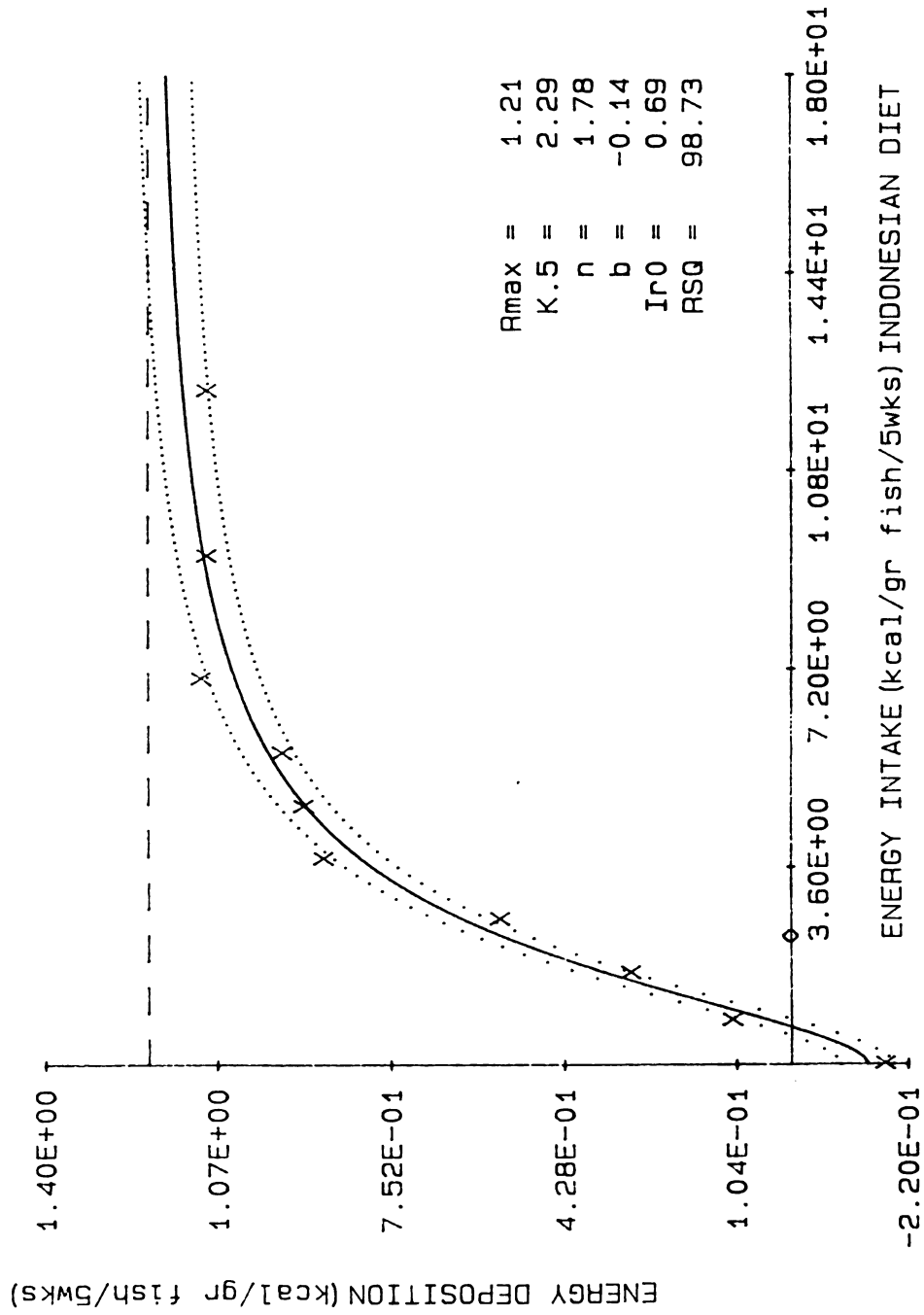


Figure 10. Theoretical nutrient response curve of gross energy intake vs gross fat energy deposition of *Q. niloticus* fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

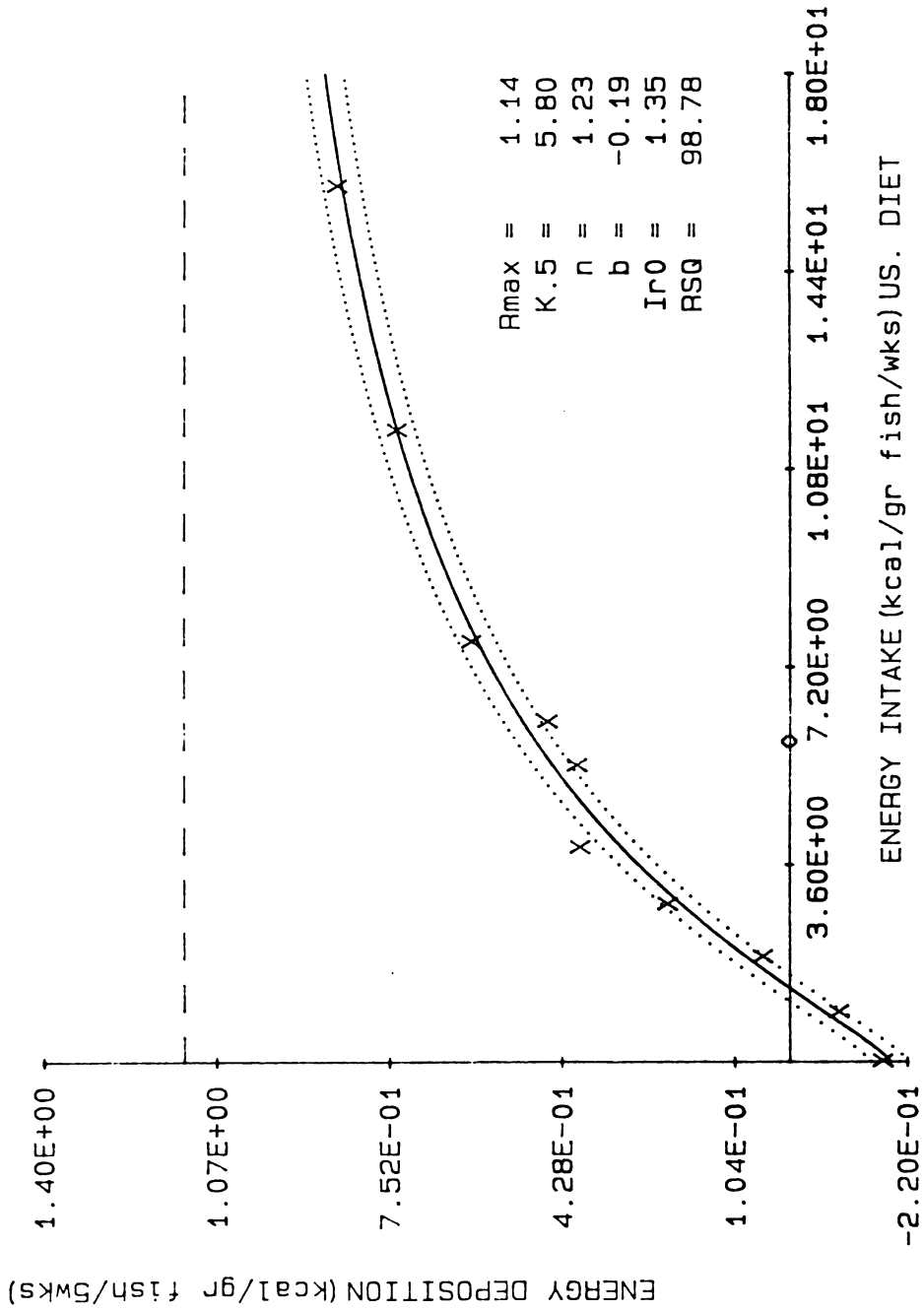


Figure 11. Theoretical nutrient response curve of gross energy intake vs gross fat energy deposition of *O. niloticus* fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

Table 17. Parameters derived from fitting dietary gross energy (kcal/g/five weeks) intake and total energy deposition kcal per fish for a five-week period.

Source of Diet	$R_{\max}^1$	$K0.5^2$	b^3	a^4	$[r=0]^5$	$\% BW^6$	$I_{\max}^7$	$\% BW^6$	$R_{\max}^8$	$R_{\max}^9$	$R_{\max.5}^{10}$
HONDURAS	ab 1.14 ± 0.18	bc 4.49 ± 1.07	a -0.09 ± 0.06	1.54	0.89	0.73	2.99	1.903	0.34	0.14	0.14
THAILAND	a 1.03 ± 0.15	ab 3.1 ± 0.58	a -0.17 ± 0.06	1.61 ± 0.9	1.01	0.67	2.28	0.97	0.29	0.20	0.19
PANAMA	b 1.33 ± 0.12	a 2.9 ± 0.46	a -0.2 ± 0.94	1.16	0.56	0.39	0.6	0.42	1.19	0.35	0.26
INDONESIA	ab 1.21 ± 0.08	a 2.9 ± 0.25	a 0.14 ± 0.06	1.78	0.69	0.42	1.2	0.73	0.45	0.29	0.23
U.S.A.	ab 1.14 ± 0.21	c 5.79 ± 1.67	a 0.19 ± 0.04	1.23	1.35	0.73	1.77	0.93	6.18	0.14	0.11

1 $R_{\max}$: The maximum theoretical response.

2 $K0.5$: The intake level at half maximum response.

3 b : The response at zero intake level.

4 a : The kinetic order.

5 $[r=0]$: The intake at zero response (maintenance).

6 $\% BW$: Daily food intake as a percentage of body weight for the previous column.

7 $I_{\max}$: The intake at maximum efficiency.

8 $R_{\max}$: The response at maximum efficiency.

9 $R_{\max}$: Maximum efficiency.

10 $R_{\max.5}$: Overall efficiency.

b: At zero dietary energy intake level (b) there was no significant difference between diets as was expected (control group).

The value of n , the kinetic order resulted in a sigmoidal ($n > 1$) curve shape for energy response in all the test diets.

The amount of dietary energy intake that produced zero energy deposition in the fish bodies ($I_r = 0$, the maintenance energy level of each diet) was the lowest in the fish fed the PD followed by fish fed the ID, HD, TD, and AD, respectively. Tilapia achieved maximum efficiency of converting the dietary energy to body energy (ME) when they were fed ID. Fish fed PD had lower ME values than that of ID. Fish fed TD had lower ME values than that of PD. Fish fed the AD, and HD had similar ME values and were the least efficient when compared to fish fed all other test diets. When the fish fed total dietary energy equivalent to half maximum response energy deposition the overall energy efficiency had slight change when compared to the maximum efficiency. Fish fed ID became the most energy efficient. Fish fed the PD showed a sharp decline in energy efficiency from the maximum efficiency. Fish fed the three other diets had a slight change in their energy efficiency level. All other diets had lower crude fat content than the recommended level.

Carbohydrate content of the test diets ranged from 35 to 42 percent of the diet. O. niloticus can efficiently utilize dietary carbohydrates up to 40 percent of the diet (Anderson et al. 1984). Dietary fiber contents ranged from 5.87 to 13.01. The recommended level for tilapia is 8 percent (Jauncey and Ross 1982). The HD, TD, and AD had higher dietary fiber levels than the recommended one. The

ID had a similar fiber level to the recommended level. The PD had a lower dietary fiber level than the recommended one.

Crude Protein Response

Tables 18, 19, 20, 21 and 22 show the sloping lines for the amount of protein intake and deposition as fish protein in (mgr/gr fish/five-week period) for each diet. Figures 12, 13, 14, 15 and 16 show the above information graphically. Table 29 shows a summary of the parameters and the parameter derivatives of the four parameter model that is achieved by the fish. The maximum amount of protein deposition in fish bodies ($R_{\max}$) for fish fed the experimental diet varied significantly. Fish fed the ID had the highest $R_{\max}$ value when compared to all other test diets. Protein deposition of fish fed the AD, PD, and HD were not significantly different in terms of their $R_{\max}$. The amount of dietary protein fed in order to deposit half the protein deposited in the fish in $R_{\max}$ for each diet is represented by $K_{0.5}$ value. Fish fed the TD had the least $K_{0.5}$ value of all those fed other test diets. Fish fed the Hd, PD, Id, and AD were not significantly different in terms of their $K_{0.5}$ values. Fish fed zero protein were all not significantly different from each other in terms of the negative protein deposition value (b).

Dietary protein levels that maintain the original body protein at maintenance level (no gain or loss of body protein) is represented by $I_r=0$. Fish fed the TD had the least (best) value of $I_r=0$. Fish fed

Table 18. Crude protein intake, observed deposition (ro), and caculated deposition (rc) of *O. niloticus* fed varying percentages of the Honduran tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-28.0000	-21.97
0.5	42.0000	-2.0000	-12.01
1.0	88.0000	5.0000	6.92
1.5	136.0000	27.0000	26.09
2.0	185.0000	34.0000	41.94
2.5	219.0000	46.0000	50.67
3.0	297.0000	72.0000	65.22
3.5	348.0000	79.0000	71.77
5.0	531.0000	86.0000	85.19
7.0	805.0000	88.0000	93.19

¹Daily food intake as a percentage of the wet body weight.

²Crude protein deposition (mg/g fish/five weeks).

³Total crude protein per gram of fish wet weight during the five-week period.

⁴Calculated crude protein deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 19. Crude protein intake, observed deposition (ro), and caculated deposition (rc) of *O. niloticus* fed varying percentages of the Thailand tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-20.0000	-19.25
0.5	31.0000	1.1000	1.48
1.0	43.0000	13.5000	8.90
1.5	91.0000	25.0000	29.57
2.0	134.0000	36.0000	40.11
2.5	167.0000	41.5000	45.46
3.0	203.0000	51.0000	49.67
3.5	248.0000	68.0000	53.43
5.0	349.0000	59.0000	58.57
7.0	484.0000	55.0000	62.15

¹Daily food intake as a percentage of the wet body weight.

²Crude protein deposition (mg/g fish/five weeks).

³Total crude protein per gram of fish wet weight during the five-week period.

⁴Calculated crude protein deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 20. Crude protein intake, observed deposition (ro), and caculated deposition (rc) of O. niloticus fed varying percentages of the Panamanian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-18.1300	-16.05
0.5	45.3000	7.5400	3.28
1.0	96.0000	29.200	26.14
1.5	145.0000	35.0000	43.07
2.0	200.0000	52.0000	56.87
2.5	261.0000	69.0000	67.70
3.0	293.0000	75.0000	72.07
3.5	380.0000	89.0000	80.93
5.0	541.0000	91.0000	90.58
7.0	792.0000	93.0000	98.03

¹Daily food intake as a percentage of the wet body weight.

²Crude protein deposition (mg/g fish/five weeks).

³Total crude protein per gram of fish wet weight during the five-week period.

⁴Calculated crude protein deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 21. Crude protein intake, observed deposition (ro), and caculated deposition (rc) of O. niloticus fed varying percentages of the Indonesian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-14.50000	-14.98
0.5	58.0000	1.0000	1.68
1.0	126.0000	26.0000	25.88
1.5	193.0000	43.0000	46.06
2.0	281.0000	74.0000	66.04
2.5	353.0000	78.0000	78.04
3.0	426.0000	81.0000	87.34
3.5	528.0000	97.0000	96.97
5.0	696.0000	108.0000	107.50
7.0	958.0000	118.0000	116.96

¹Daily food intake as a percentage of the wet body weight.

²Crude protein deposition (mg/g fish/five weeks).

³Total crude protein per gram of fish wet weight during the five-week period.

⁴Calculated crude protein deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 22. Crude protein intake, observed deposition (ro), and caculated deposition (rc) of O. niloticus fed varying percentages of the U.S. tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-19.40000	-19.81
0.5	40.8000	-9.8000	-8.37
1.0	86.90000	5.70000	6.36
1.5	130.0000	24.50000	18.83
2.0	177.5000	29.90000	30.06
2.5	229.0000	31.80000	40.05
3.0	280.0000	46.9000	48.03
3.5	329.0000	60.4000	54.22
5.0	515.6000	69.8000	69.75
7.0	767.4000	79.9000	80.59

¹Daily food intake as a percentage of the wet body weight.

²Crude protein deposition (mg/g fish/five weeks).

³Total crude protein per gram of fish wet weight during the five-week period.

⁴Calculated crude protein deposition from the saturation kinetic equation (Morgan et al. 1975).

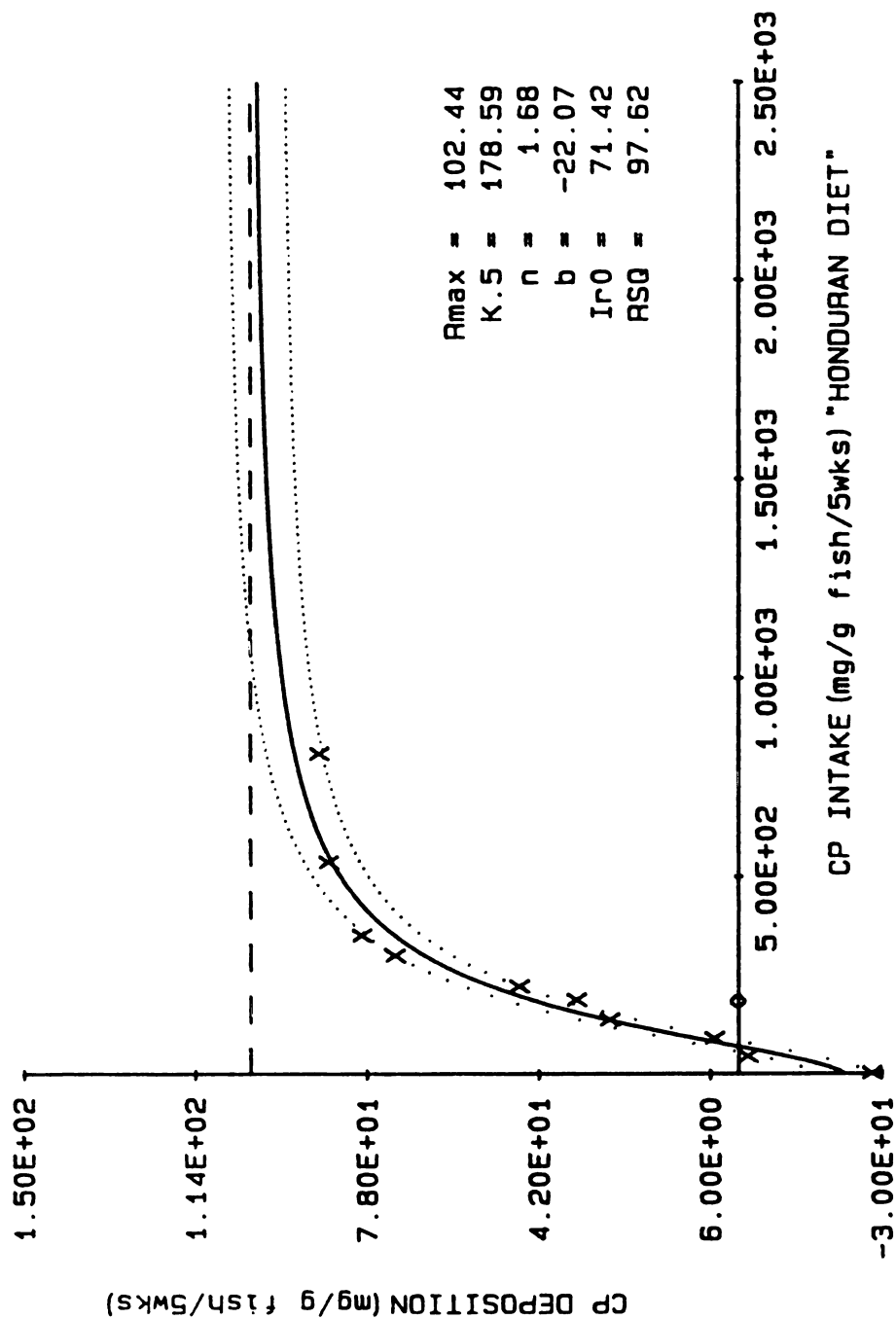


Figure 12. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of *O. niloticus* fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

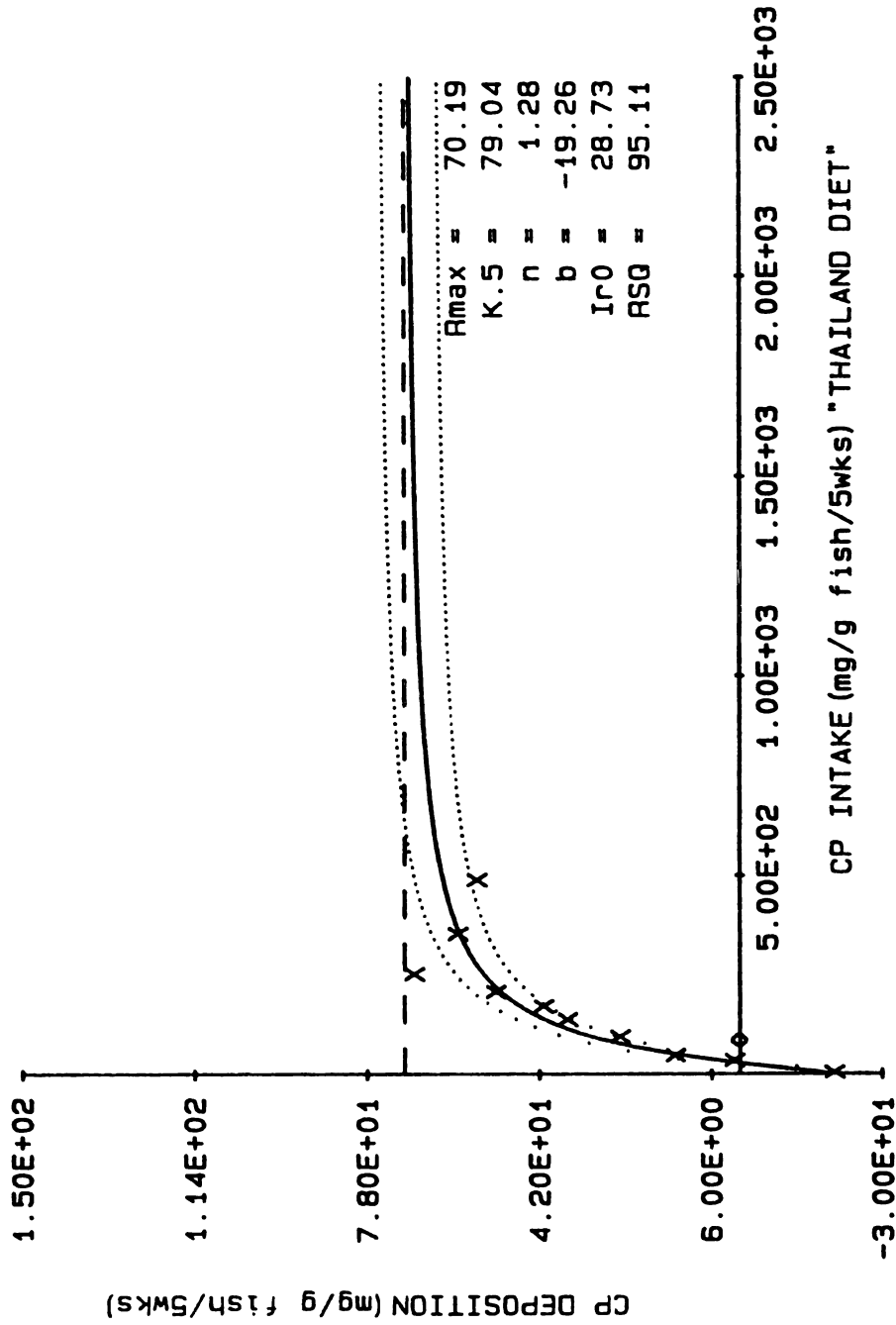


Figure 13. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of *Q. nilotica* fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $r=3$).

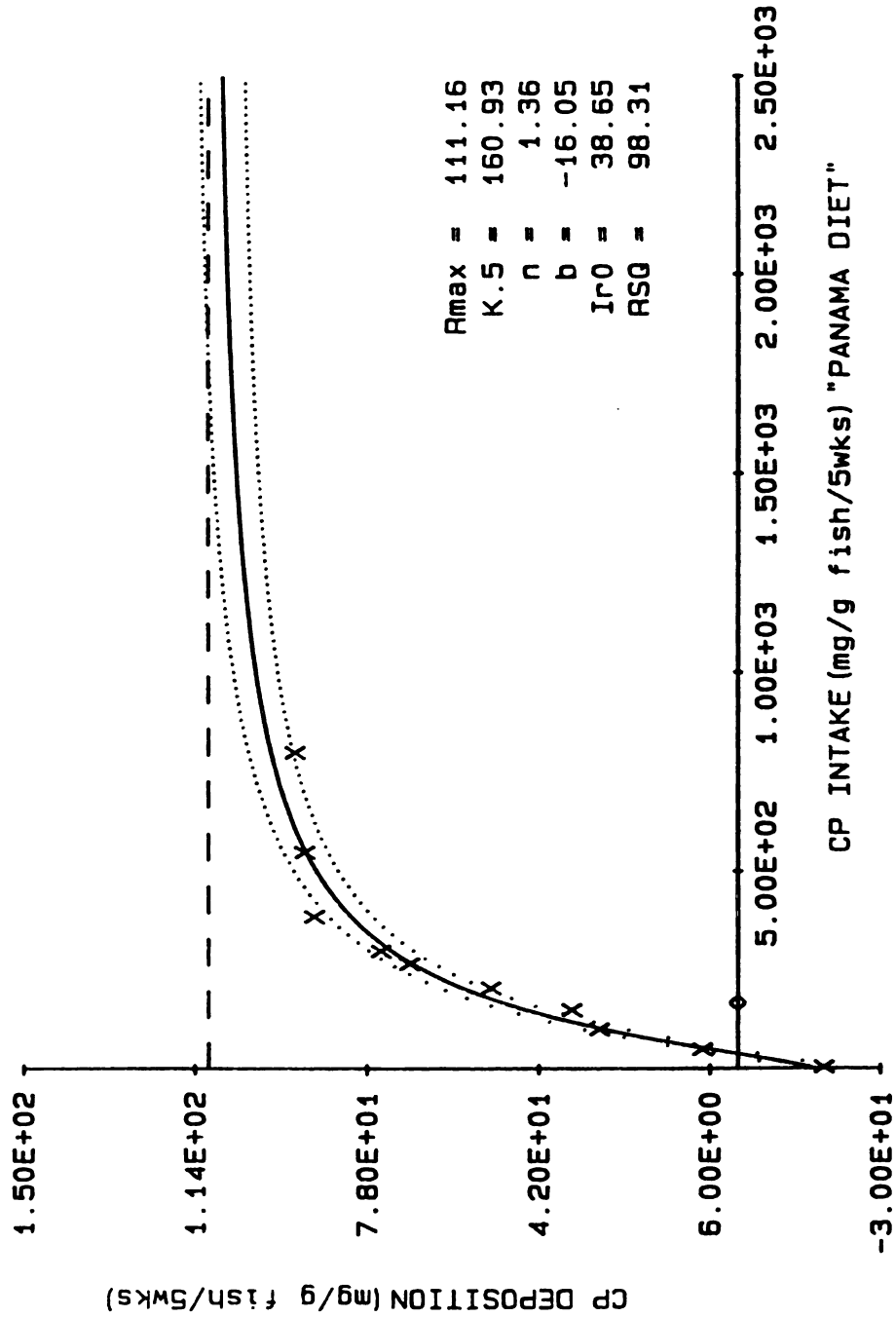


Figure 14. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of *O. niloticus* fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

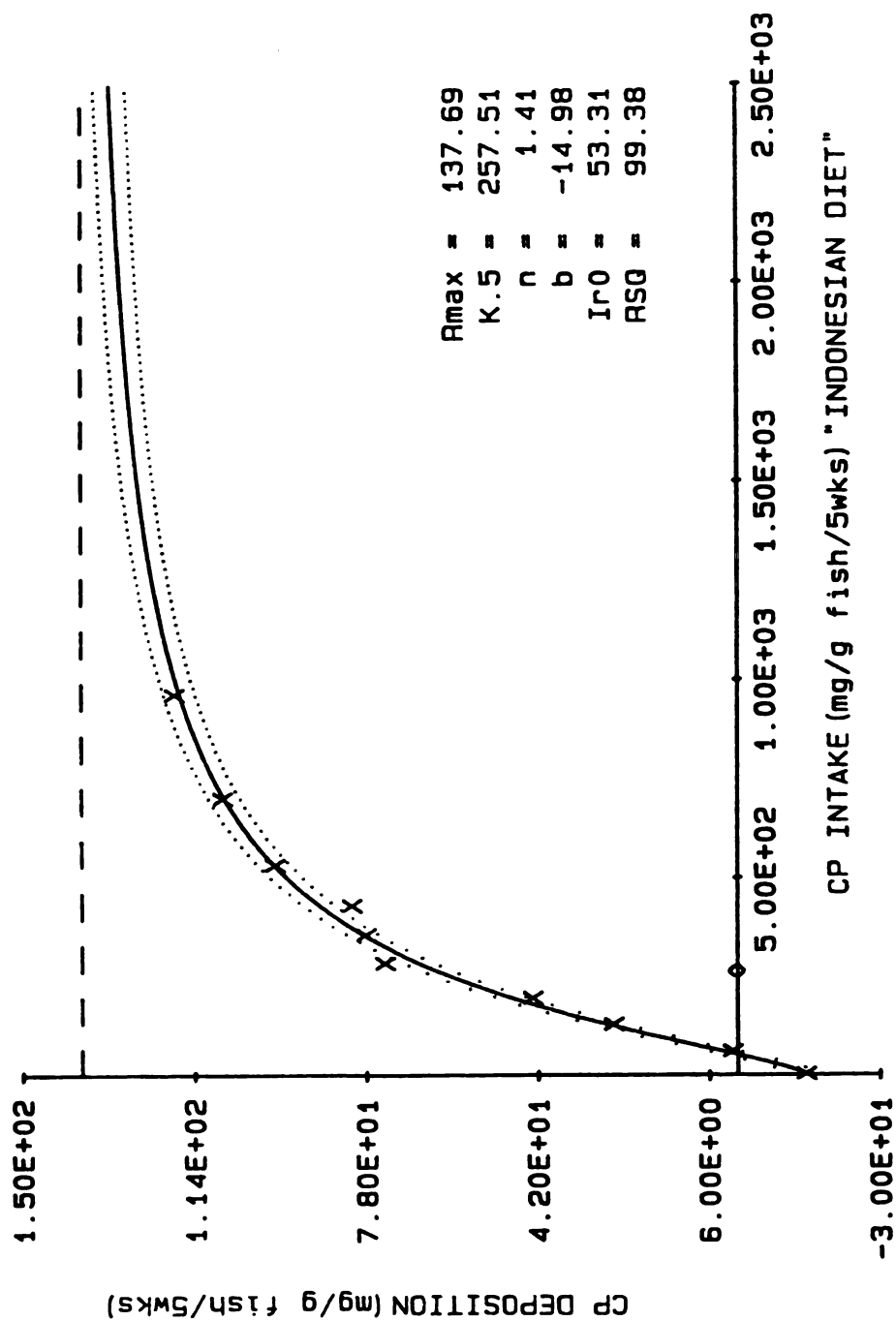


Figure 15. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of *Q. niloticus* fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

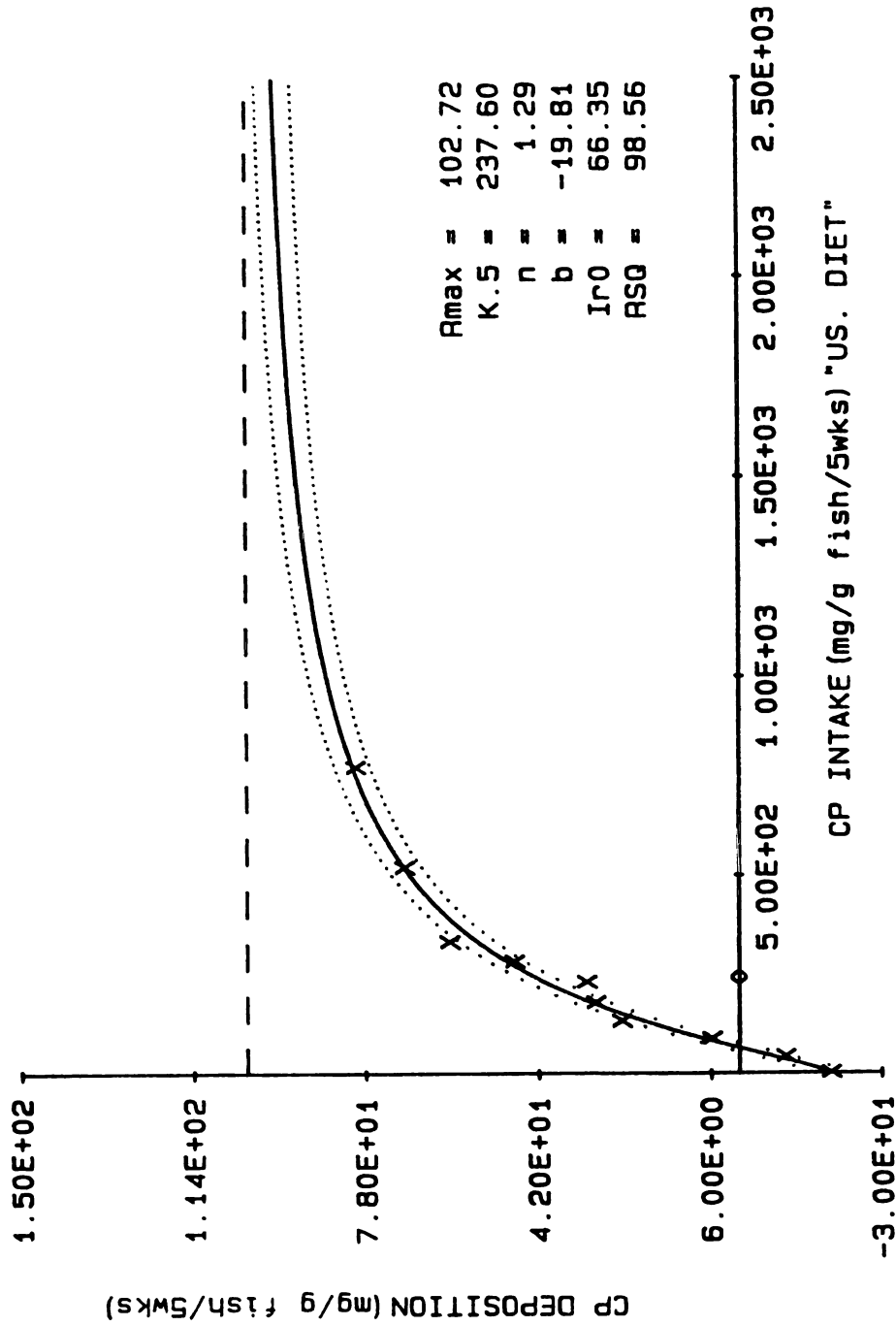


Figure 16. Theoretical nutrient response curve of crude protein intake vs crude protein deposition of *O. niloticus* fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

Table 23. Parameters derived from fitting dietary protein intake (mg protein per g of fish/five-week period) and protein deposition (mg protein/g fish/five-week period) for each of the five tilapia practical diets.

Source of Diet	$R_{\max}^1$	$K0.5^2$	b^3	a^4	$Ir=0^5$	$\% BW^6$	I_{enx}^7	$\% BW^6$	R_{enx}^8	R_{enx}^9	R_{enx}^{10}
HONDURAS	b 102.33 ± 13.14	bc 178.86 ± 29.32	a -21.97 ± 7.02	1.68 ± 0.43	71.75	0.76	142.79	1.6	28.53	0.35	0.35
THAILAND	a 70.03 ± 14.33	a 78.62 ± 27.42	a -19.25 ± 17.49	1.29 ± 0.46	28.78	0.46	29.61	0.48	0.56	0.67	0.57
PANAMA	b 111.7 ± 12.95	b 160.94 ± 30.04	a -16.05 ± 5.93	1.36 ± 0.29	38.64	0.42	75.24	1.32	17.38	0.44	0.39
INDONESIA	c 137.7 ± 11.76	d 257.29 ± 33.3	a -14.98 ± 4.19	1.41 ± 0.2	66.47	.026	136.4	1.1	29.31	0.32	0.29
U.S.A.	b 102.72 ± 17.45	bed 237.6 ± 58.46	a -19.84 ± 4.65	1.29 ± 0.28	66.35	0.77	91.02	1.1	7.73	0.30	0.25

¹ $R_{\max}$: The maximum theoretical response.

² $K0.5$: The intake level at half maximum response.

³ b : The response at zero intake level.

⁴ a : The kinetic order.

⁵ $Ir=0$: The intake at zero response (maintenance).

⁶ $\% BW$: Daily food intake as a percentage of body weight for the previous column.

⁷ I_{enx} : The intake at maximum efficiency.

⁸ R_{enx} : The response at maximum efficiency.

⁹ R_{enx} : Maximum efficiency.

¹⁰ $R_{\text{enx}}^{0.5}$: Overall efficiency.

the PD had higher $I_r=0$ values than the ones fed the TD. Fish fed the ID, AD, and HD had almost twice the value of those fed the TD in terms of their $I_r=0$ value. The maximum efficiency of converting the dietary protein to fish protein is represented by E_{mx} . Fish fed the TD were the most efficient and had the highest E_{mx} value of all fish fed other test diets. Fish fed the PD had a much lower E_{mx} value than those fed the TD. Fish fed the HD, ID and AD had, respectively lower E_{mx} values. The dietary protein efficiency value when fish fed at their half R_{max} value is represented by the overall efficiency value. Fish fed all the test diet had slightly lower efficiency values overall than their E_{mx} value with the same order.

Crude Fat Deposition

Tables 24, 25, 26, 27, and 28 show the amount of dietary crude fat intake and deposition in fish bodies (mgr/gr fish/five-week period) for each diet. Figures 17, 18, 19, 20 and 21 show the same information graphically. Table 24 shows a summary of the four parameters and their derivatives that are achieved by the fish.

R_{max} : represents the maximum theoretical amount of crude fat deposition of fish fed any of the experimental diets. Fish fed the TD and PD had the lowest R_{max} values when compared to fish on any other experimental diet. Fish fed the ID resulted in higher R_{max} values than those fed the TD and were not significantly different from those

Table 24. Crude fat intake, observed deposition (ro) and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Honduran tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-8.0000	-8.08
0.5	10.0000	-3.0000	-2.68
1.0	20.0000	4.0000	3.48
1.5	31.0000	11.0000	10.18
2.0	43.0000	15.0000	17.09
2.5	50.0000	20.0000	20.89
3.0	68.0000	32.0000	29.88
3.5	80.0000	36.0000	35.25
5.0	131.0000	52.0000	53.49
7.0	198.000	70.0000	69.52

¹Daily food intake as a percentage of the wet body weight.

²Crude fat intake (mg/g fish/five weeks).

³Total crude fat deposition per gram of fish wet weight during the five-week period.

⁴Calculated crude fat deposition from the kinetic equation (Morgan et al. 1975).

Table 25. Crude fat intake, observed deposition (ro) and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Thailand tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-8.0000	-6.26
0.5	17.0000	0.5000	-1.82
1.0	35.0000	7.0000	6.49
1.5	53.0000	16.0000	15.01
2.0	71.0000	19.0000	22.43
2.5	94.0000	28.0000	29.92
3.0	110.0000	33.0000	33.99
3.5	135.0000	45.0000	38.88
5.0	190.0000	46.0000	45.61
7.0	264.0000	48.0000	50.24

¹Daily food intake as a percentage of the wet body weight.

²Crude fat intake (mg/g fish/five weeks).

³Total crude fat deposition per gram of fish wet weight during the five-week period.

⁴Calculated crude fat deposition from the kinetic equation (Morgan et al. 1975).

Table 26. Crude fat intake, observed deposition (ro) and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Panamanian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-10.0000	-7.9
0.5	11.0000	4.0000	0.60
1.0	23.0000	16.0000	13.61
1.5	35.0000	21.0000	25.61
2.0	48.0000	31.0000	35.71
2.5	62.0000	42.0000	44.21
3.0	71.0000	58.0000	48.54
3.5	91.0000	57.0000	48.54
5.0	128.0000	62.0000	64.13
7.0	188.0000	70.000	70.85

¹Daily food intake as a percentage of the wet body weight.

²Crude fat intake (mg/g fish/five weeks).

³Total crude fat deposition per gram of fish wet weight during the five-week period.

⁴Calculated crude fat deposition from the kinetic equation (Morgan et al. 1975).

Table 27. Crude fat intake, observed deposition (ro) and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Indonesian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-7.0000	-6.01
0.5	15.0000	7.0000	4.75
1.0	32.0000	21.0000	21.75
1.5	51.0000	33.0000	37.48
2.0	72.0000	58.0000	50.49
2.5	93.0000	55.0000	59.70
3.0	109.0000	63.0000	64.92
3.5	135.0000	75.0000	71.17
5.0	177.0000	78.0000	77.65
7.0	244.0000	82.0000	83.35

¹Daily food intake as a percentage of the wet body weight.

²Crude fat intake (mg/g fish/five weeks).

³Total crude fat deposition per gram of fish wet weight during the five-week period.

⁴Calculated crude fat deposition from the kinetic equation (Morgan et al. 1975).

Table 28. Crude fat intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of U.S. tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	- 8.0000	-7.88
0.5	18.0000	- 4.0000	-3.92
1.0	37.0000	2.0000	0.84
1.5	56.0000	5.0000	5.68
2.0	76.0000	10.0000	10.73
2.5	98.0000	16.0000	16.15
3.01	120.0000	20.0000	21.37
3.5	141.0000	29.0000	26.16
5.0	218.0000	41.0000	42.07
7.0	329.0000	61.0000	60.8

¹Daily food intake as a percentage of the wet body weight.

²Crude fat intake (mg/g fish/five weeks).

³Total crude fat deposition per gram of fish wet weight during the five-week period.

⁴Calculated crude fat deposition from the kinetic equation (Morgan et al. 1975).

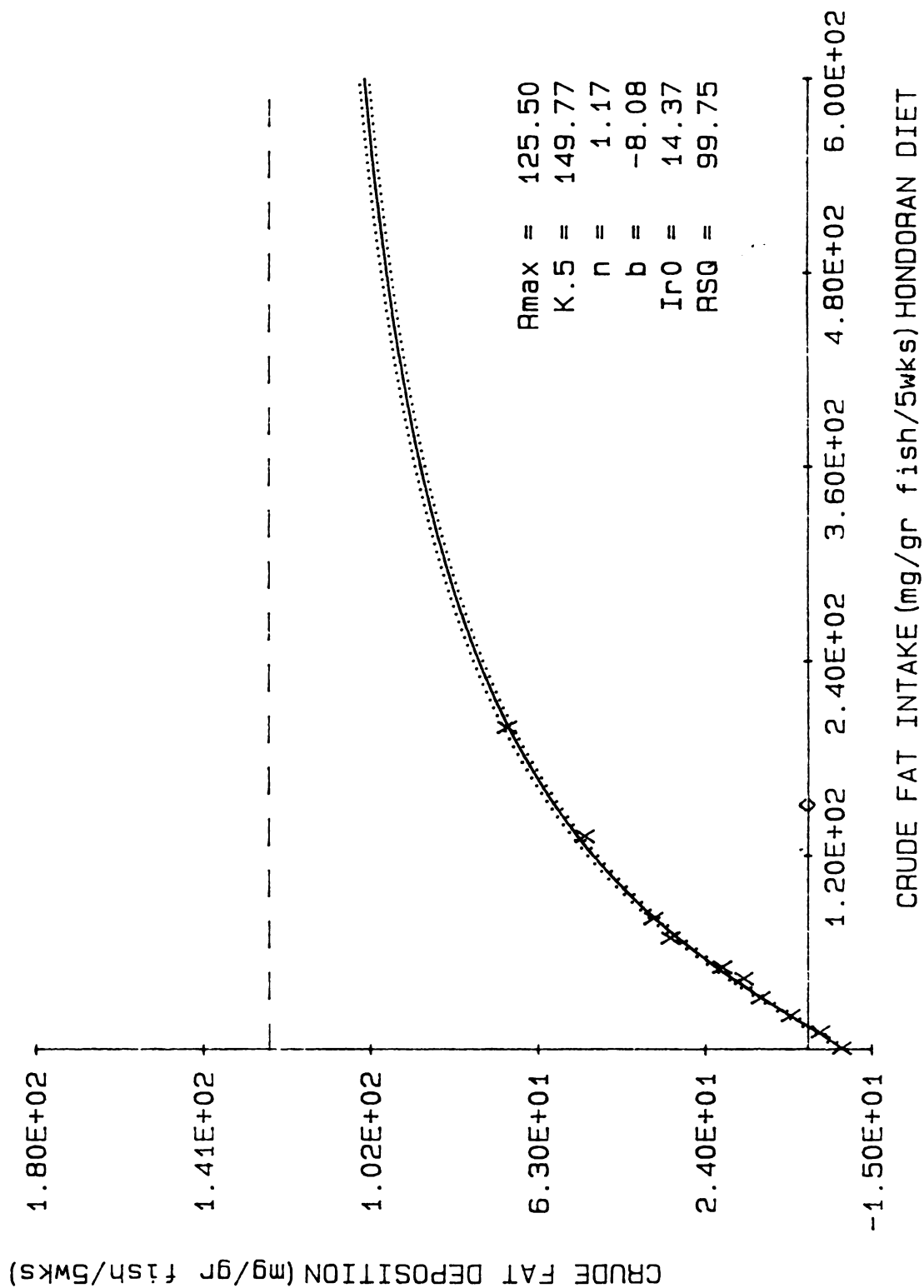


Figure 17. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of *Q. niloticus* fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

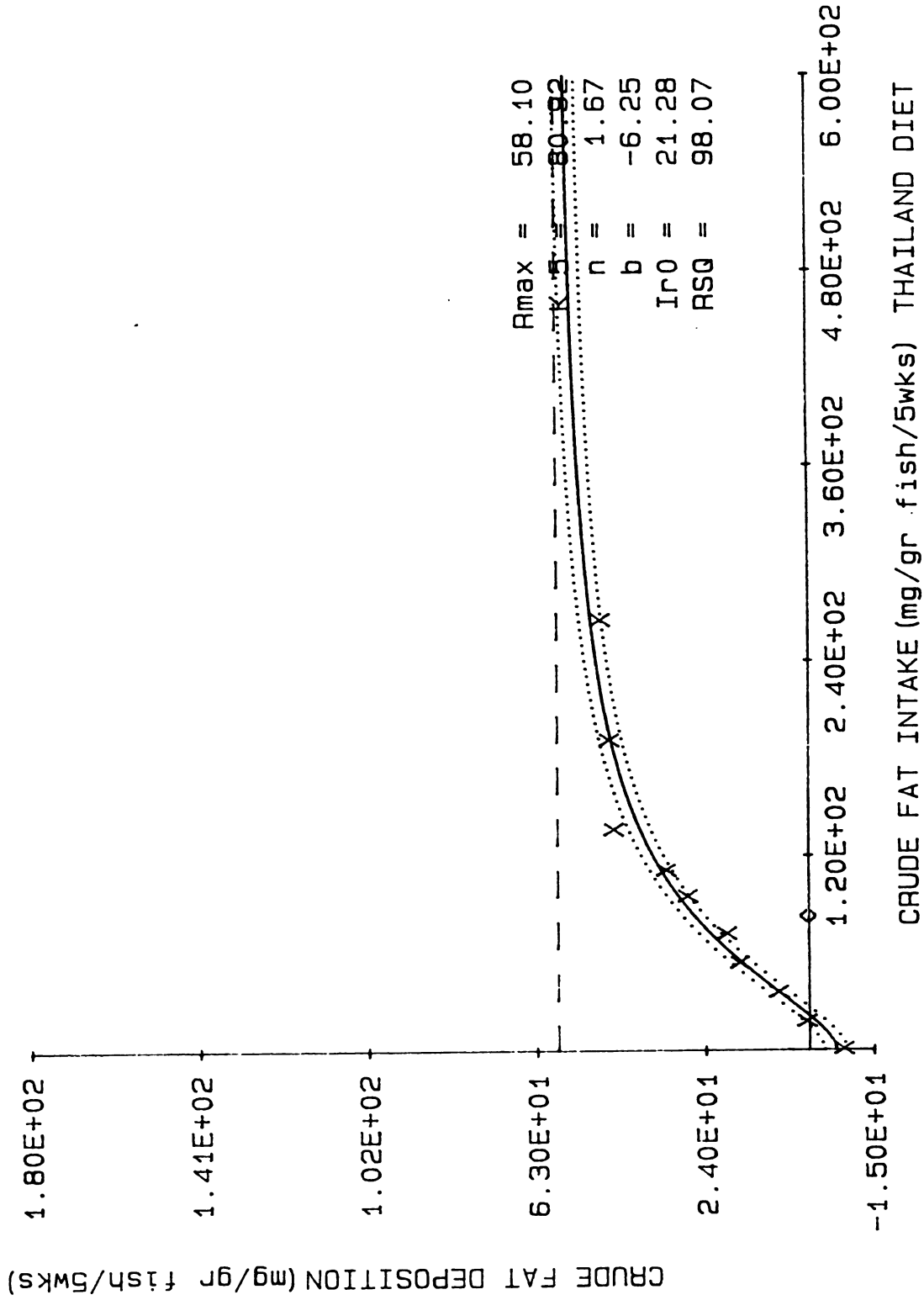


Figure 18. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of *Q. niloticus* fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

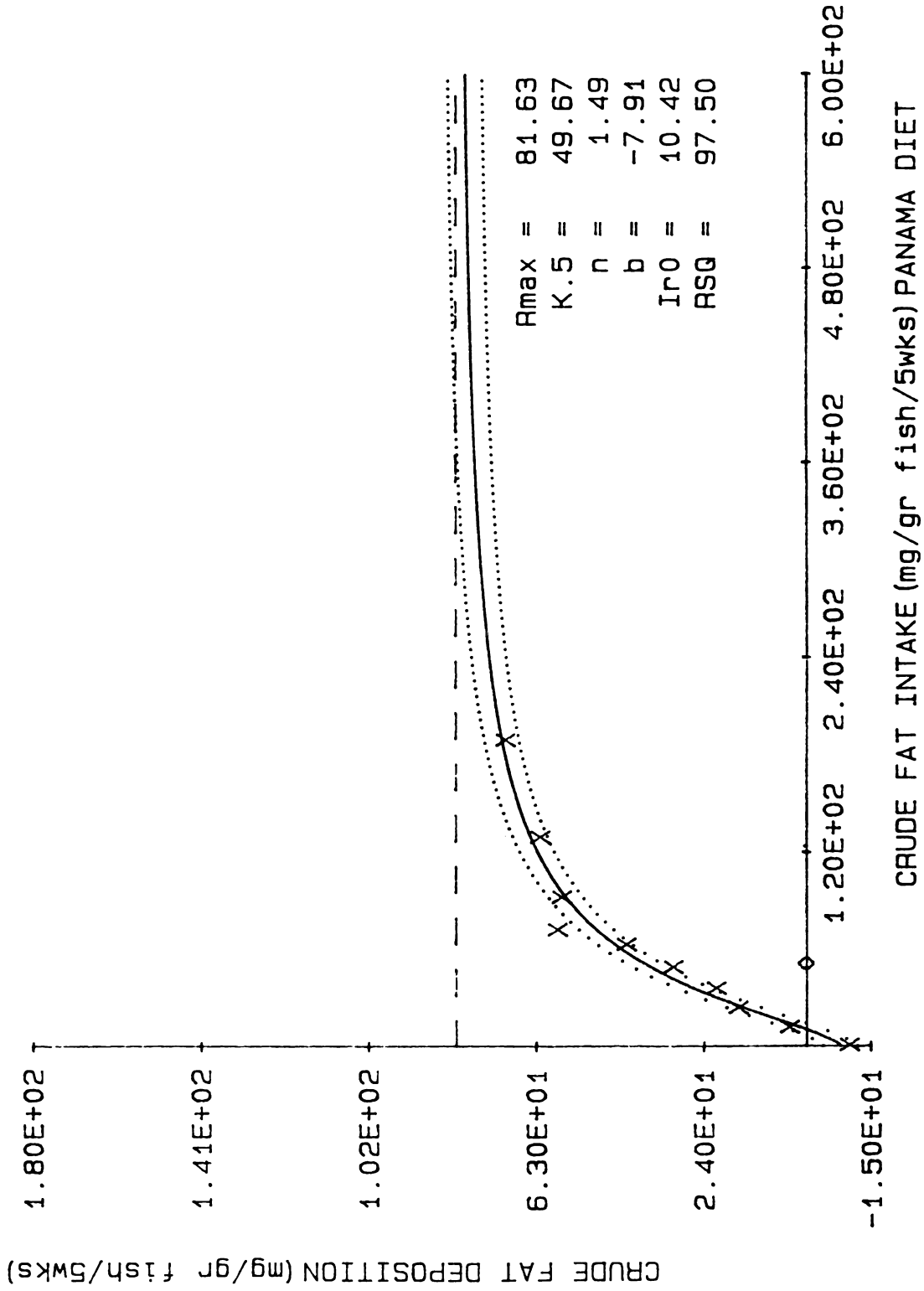


Figure 19. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of *O. niloticus* fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

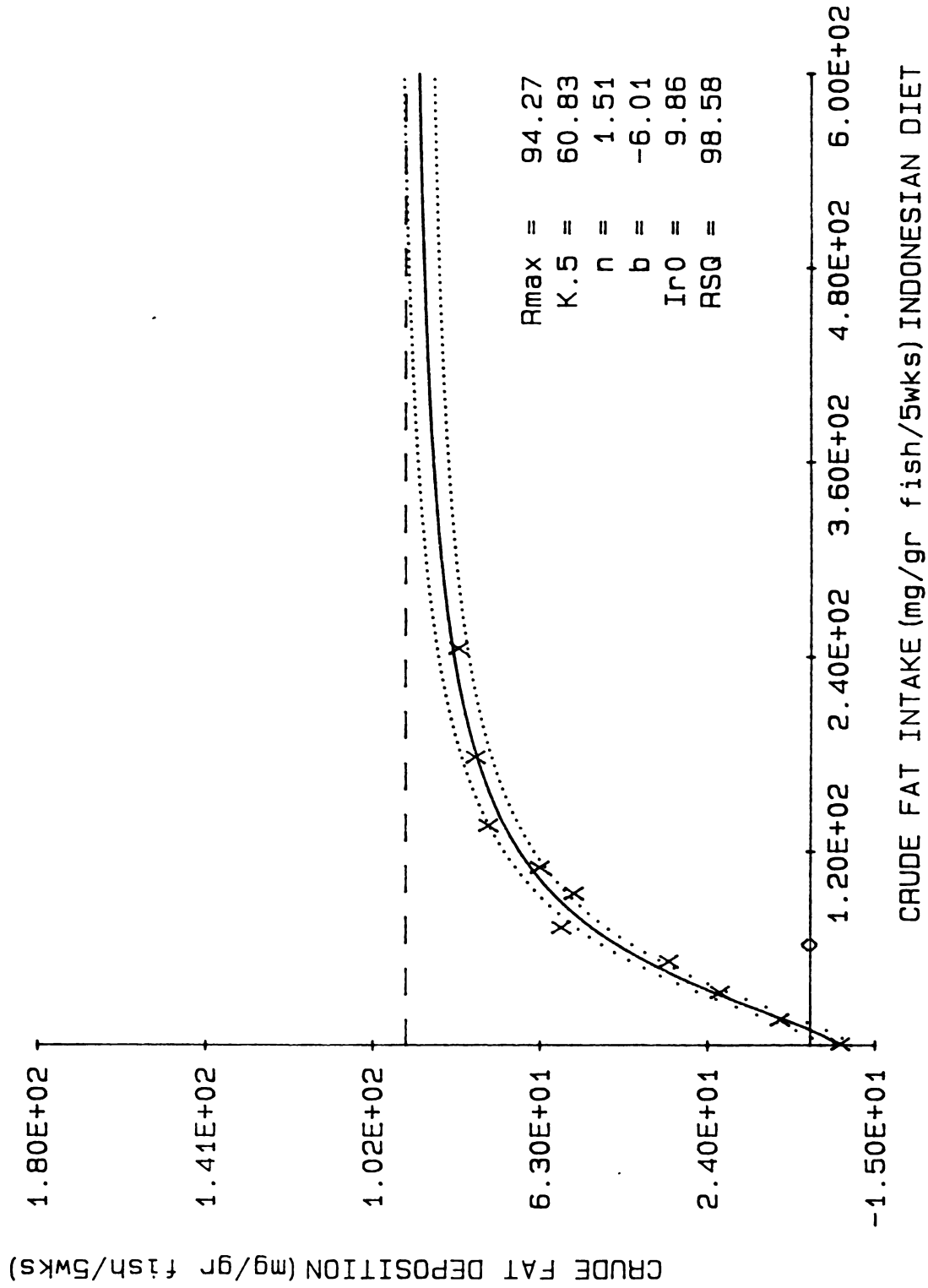


Figure 20. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of *O. niloticus* fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

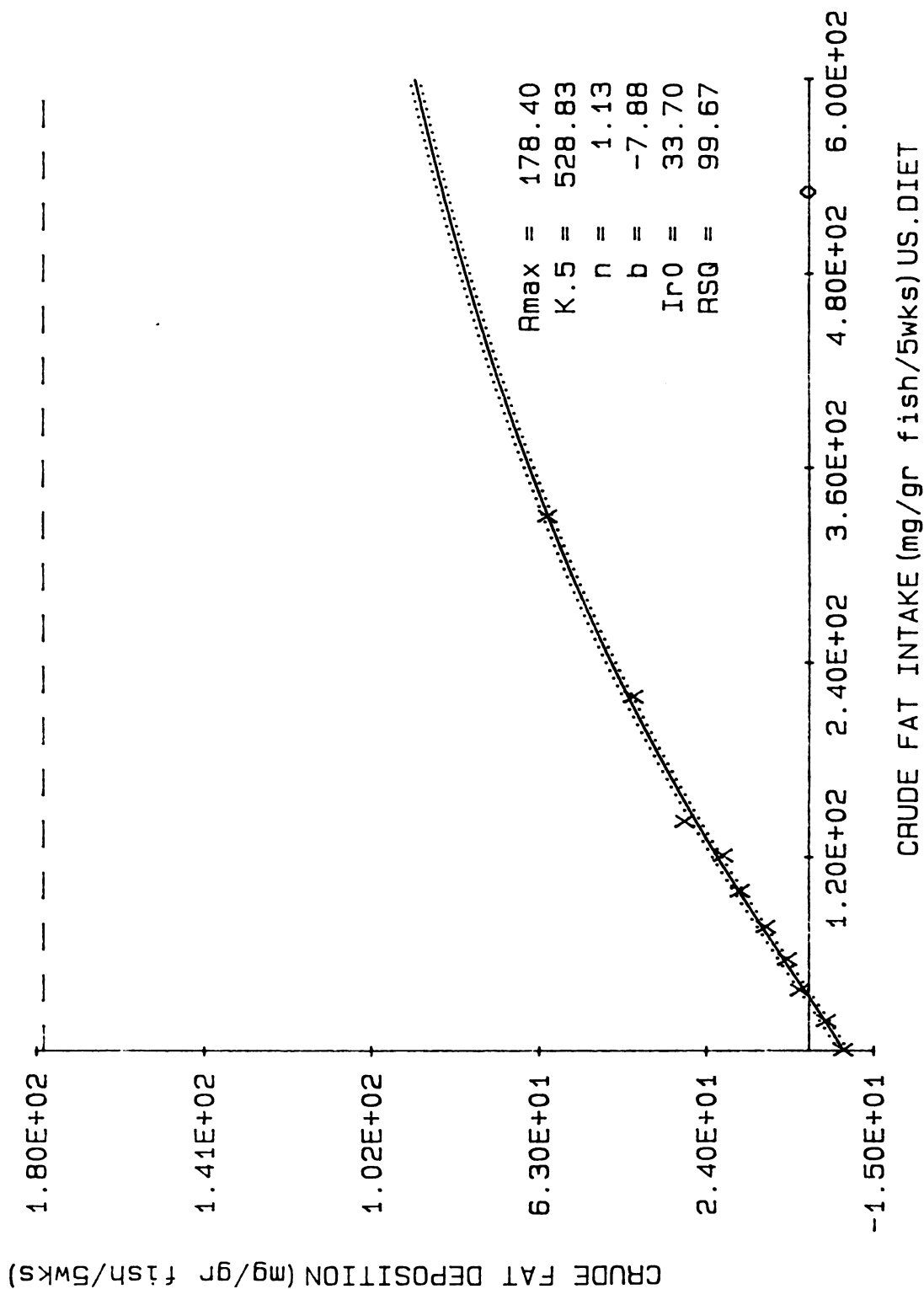


Figure 21. Theoretical nutrient response curve of crude fat intake vs crude fat deposition of *Q. niloticus* fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

Table 29. Parameters derived from the model equation for dietary crude fat deposition vs. dietary crude fat intake (mg/g fish/five weeks).

Source of Diet	$R_{\max}^1$	$K0.5^2$	b^3	a^4	$Ir=0^5$	$\% BW^6$	I_{enx}^7	$\% BW^8$	R_{enx}^8	R_{enx}^9	R_{enx}^{10}
HONDURAS	125.5 ± 22.07	149.77 ± 41.96	-8.08 ± 1.4	1.17 ± 0.13	14.34	0.72	32.96	1.6	11.34	0.59	0.45
THAILAND	58.1 ± 8.3	80.93 ± 14.83	-6.26 ± 0.9	1.67 ± 3.09	21.27	0.62	63.54	1.8	19.52	0.41	0.40
PANAMA	81.61 ± 12.62	49.66 ± 11.09	-7.9 ± 4.94	1.5 ± 0.41	10.42	0.47	31.05	1.3	21.75	0.96	0.90
INDONESIA	94.27 ± 10.16	60.84 ± 10.09	-6.01 ± 4.35	1.51 ± 0.32	9.86	0.32	39.14	1.2	27.99	0.86	0.82
U.S.A.	178.4 ± 8.136	528.83 ± 346.88	-7.88 ± 1.38	1.13	33.7	0.91	89.12	2.3	13.98	0.25	0.18

- 1 $R_{\max}$: The maximum theoretical response.
- 2 $K0.5$: The intake level at half maximum response.
- 3 b : The response at zero intake level.
- 4 a : The kinetic order.
- 5 $Ir=0$: The intake at zero response (maintenance).
- 6 $\% BW$: Daily food intake as a percentage of body weight for the previous column.
- 7 I_{enx} : The intake at maximum efficiency.
- 8 R_{enx} : The response at maximum efficiency.
- 9 R_{enx} : Maximum efficiency.
- 10 R_{enx}^{10} : Overall efficiency.

fed the PD and TD. Fish fed the AD had the highest $R_{\max}$ value of all diets and were not significantly different from those fed the HD and ID.

The amount of dietary fat fed that resulted in deposition half of the $R_{\max}$ value of crude fat deposition in fish bodies is represented by $K0.5$. The fish fed the PD had the lowest (best) $K0.5$ value as compared to all other test diets. Fish fed the HD had significantly higher ($P < 0.05$) $K0.5$ values than the ones fed the PD and TD. Fish fed the AD had the highest $K0.5$ value of all those fed any of the other diets. Fish fed zero dietary fat had a nonsignificant difference in terms of the negative fat deposition (b). The kinetic order (n) shows a sigmoidal ($n > 1$) curve relationship between dietary fat intake and deposition in fish bodies. The amount of dietary fat fed to maintain fish body fat at zero fat deposition (maintenance) is represented by $I_r=0$. The fish fed the ID had the lowest $I_r=0$ value. The value of $I_r=0$ went up in fish fed the PD, HD, TD and AD, respectively. The maximum efficiency of converting dietary fat to fish body fat represented by ME. The fish fed the Panamanian diet had the highest $E_{\max}$ value of all diets. Then the $E_{\max}$ value went down in fish fed the ID, HD, TD and AD, respectively. The dietary fat efficiency when fish fed the $K0.5$ fat intake (the overall efficiency) as slightly lower than the $E_{\max}$ values of each diet with the same order between diets.

Dietary Minerals Content of the Test Diets

Dietary calcium, phosphorus, magnesium and zinc content of the test diets and the recommended levels for tilapia (Jauncy and Ross 1982) are listed in Table 30. Test feeds contained much higher calcium levels than the recommended one. The ID had more than twice as much calcium as any other diet. The TD and AD had similar calcium content. The PD had slightly less calcium content than the TD and AD. The HD had the least calcium content of all feeds and was about four times the recommended level. The dietary phosphorus content of the HD, TD and PD fell within the recommended level for tilapia. The ID and AD had higher dietary phosphorus content than the recommended level. The dietary magnesium content of the TD and AD were similar to the recommended level. The HD and ID contained a little over twice the recommended level of magnesium. The ID contained more than triple the recommended level of magnesium. Dietary zinc content of all test diets were higher than the recommended level (3-8 times). The ID and PD had the highest dietary zinc content of all diets (7-8 times the recommended level). The HD, TD and AD had similar dietary zinc content (3-4 times the recommended level).

Dietary Magnesium Response

Tables 31, 32, 33, 34 and 35 show the slope of lines for dietary magnesium fed (intake) and deposition in the fish carcass. Figures 22, 23, 24, 25 and 26 show the above information, graphically. Table 36 summarizes the parameters from the saturation kinetic model. The

Table 30. Calcium, phosphorus, magnesium and zinc analysis of the tested diets (AOCA 1975).¹

Country	Calcium g/KgI	Phosphorus g/Kg	Magnesium g/Kg	Zinc g/Kg
Honduran	13.60	7.26	1.73	0.051
Thailand	19.54	6.15	0.77	0.064
Panamanian	16.95	3.61	2.54	0.10
Indonesia	40.83	13.28	1.37	0.120
U.S.	19.55	12.44	0.69	0.053
Recommended Levels ²				
	2.70	2.9-8.00	0.70	0.015

¹Based on dry weight basis.

²Recommended levels for tilapias (Jauncey and Ross 1982).

Table 31. Magnesium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Honduran tilapia feed.

$\% \text{ BW}^1$	Intake ²	ro ³	rc ⁴
0	0.0000	-0.29	-0.2
0.5	2.6100	-0.14	-0.1
1.0	5.6000	0.3200	0.1
1.5	8.7000	0.2600	0.4
2.0	11.1900	0.6200	0.7
2.5	13.9000	0.8000	0.8
3.0	19.0000	1.1700	0.11
3.5	22.2000	1.3000	0.12
5.0	33.9700	1.2840	0.14
7.0	51.50	1.45	0.15

¹Daily food intake as a percentage of the wet body weight.

²Magnesium intake (mb/g fish/five weeks).

³Total dietary magnesium deposition per gram of fish wet weight during the five-week period.

⁴Calculated magnesium deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 32. Magnesium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Thailand tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.4100	-0.40
0.5	13.0000	0.0170	-0.10
1.0	27.0000	0.2200	0.30
1.5	42.0000	0.4500	0.50
2.0	56.0000	0.6600	0.70
2.5	72.0000	0.7300	0.80
3.0	87.0000	0.8700	0.90
3.5	106.0000	1.2000	1.00
5.0	153.0000	1.0300	1.10
7.0	204.0000	1.1200	1.20

¹Daily food intake as a percentage of the wet body weight.

²Magnesium intake (mg/g fish/five weeks).

³Total dietary magnesium deposition per gram of fish wet weight during the five-week period.

⁴Calculated magnesium deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 33. Magnesium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Panamanian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.2600	-0.02
0.5	4.6000	0.1100	0.01
1.0	9.6000	0.7400	0.06
1.5	14.6000	0.8000	0.10
2.0	20.2000	1.1800	0.13
2.5	26.2000	1.5800	0.16
3.0	29.5500	1.9400	0.18
3.5	38.3600	2.2300	0.20
5.0	54.5000	2.1700	0.23
7.0	79.8200	2.4000	0.25

¹Daily food intake as a percentage of the wet body weight.

²Magnesium intake (mb/g fish/five weeks).

³Total dietary magnesium deposition per gram of fish wet weight during the five-week period.

⁴Calculated magnesium deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 34. Magnesium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Indonesian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.5200	-0.5
0.5	2.4200	0.0700	0.1
1.0	5.2400	0.5900	0.6
1.5	8.3200	0.9600	1.0
2.0	11.7700	1.2800	1.3
2.5	14.7400	1.5200	1.5
3.0	17.8200	1.7300	1.7
3.5	22.07	1.9800	1.9
5.0	29.0800	2.2700	2.2
7.0	40.10	1.3400	2.4

¹Daily food intake as a percentage of the wet body weight.

²Magnesium intake (mg/g fish/five weeks).

³Total dietary magnesium deposition per gram of fish wet weight during the five-week period.

⁴Calculated magnesium deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 35. Magnesium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the U.S. tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.3500	-.04
0.5	1.0500	-0.1600	-0.1
1.0	2.2300	0.2100	0.1
1.5	3.3700	0.4200	0.3
2.0	4.6200	0.4600	0.5
2.5	5.9200	0.4900	0.7
3.0	7.2600	0.7500	0.8
3.5	8.5300	1.0600	0.9
5.0	13.5400	1.1800	1.10
7.0	19.9600	1.2600	1.30

¹Daily food intake as a percentage of the wet body weight.

²Magnesium intake (mb/g fish/five weeks).

³Total dietary magnesium deposition per gram of fish wet weight during the five-week period.

⁴Calculated magnesium deposition from the saturation kinetic equation (Morgan et al. 1975).

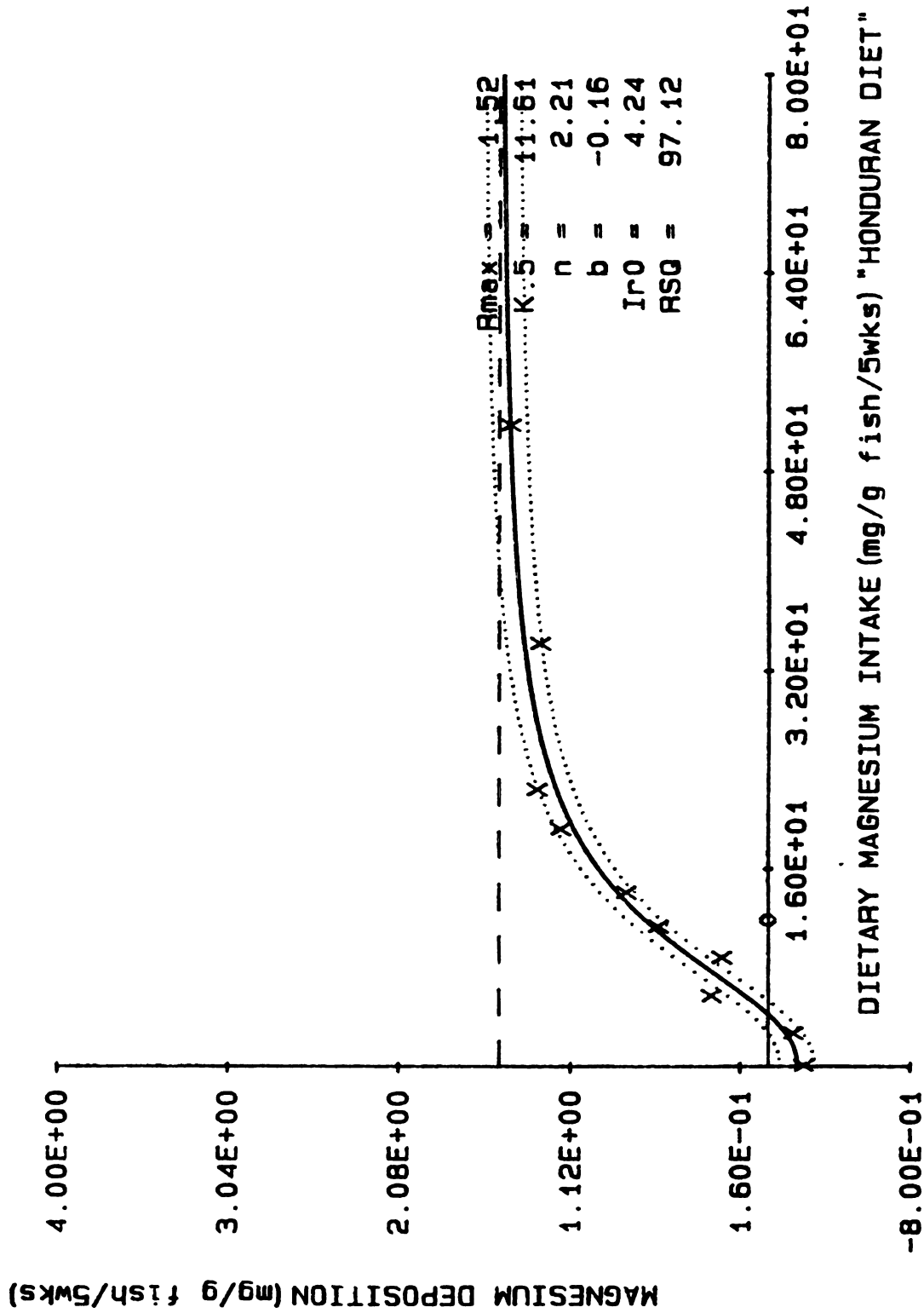


Figure 22. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of *Q. niloticus* fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

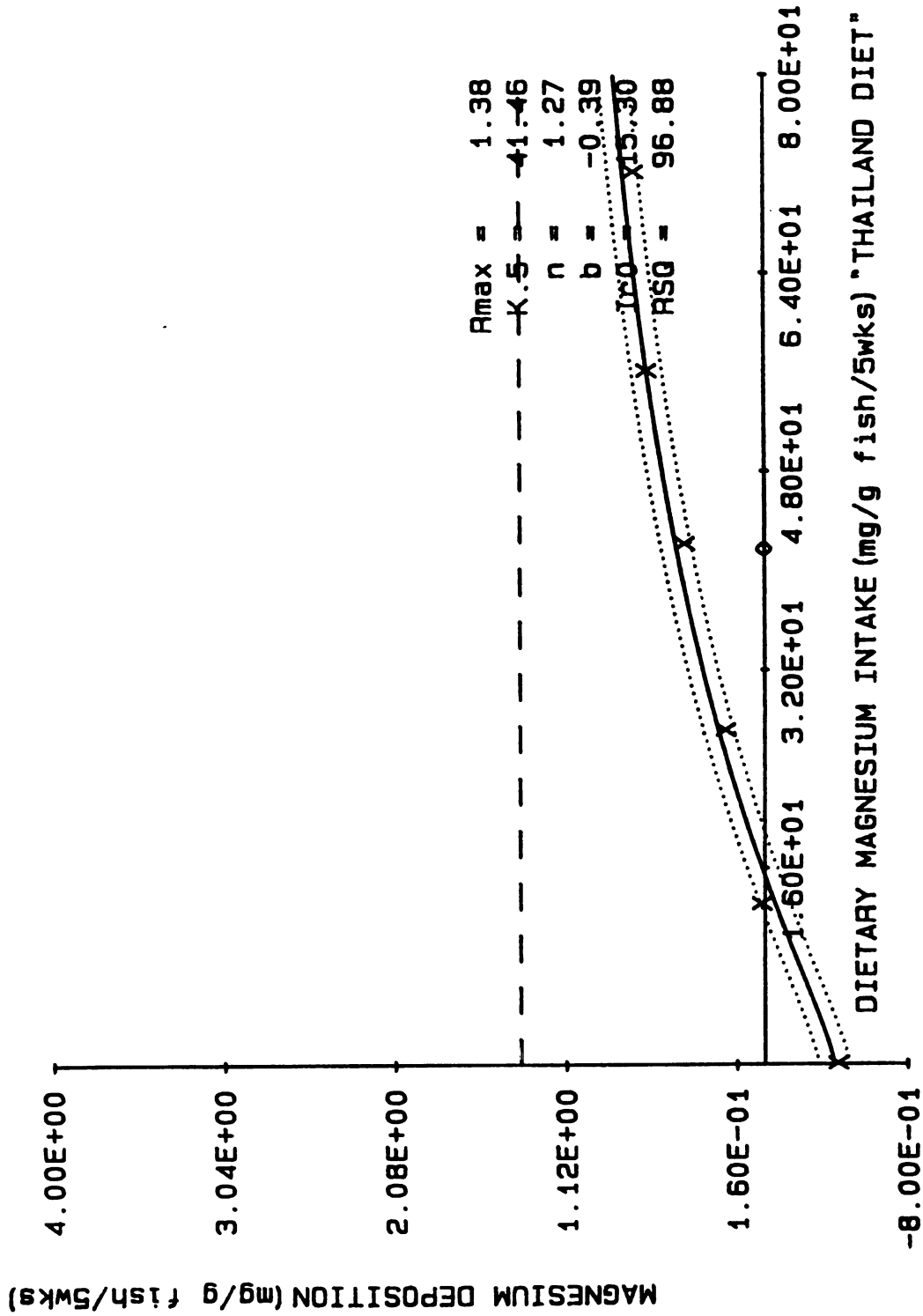


Figure 23. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of *O. niloticus* fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

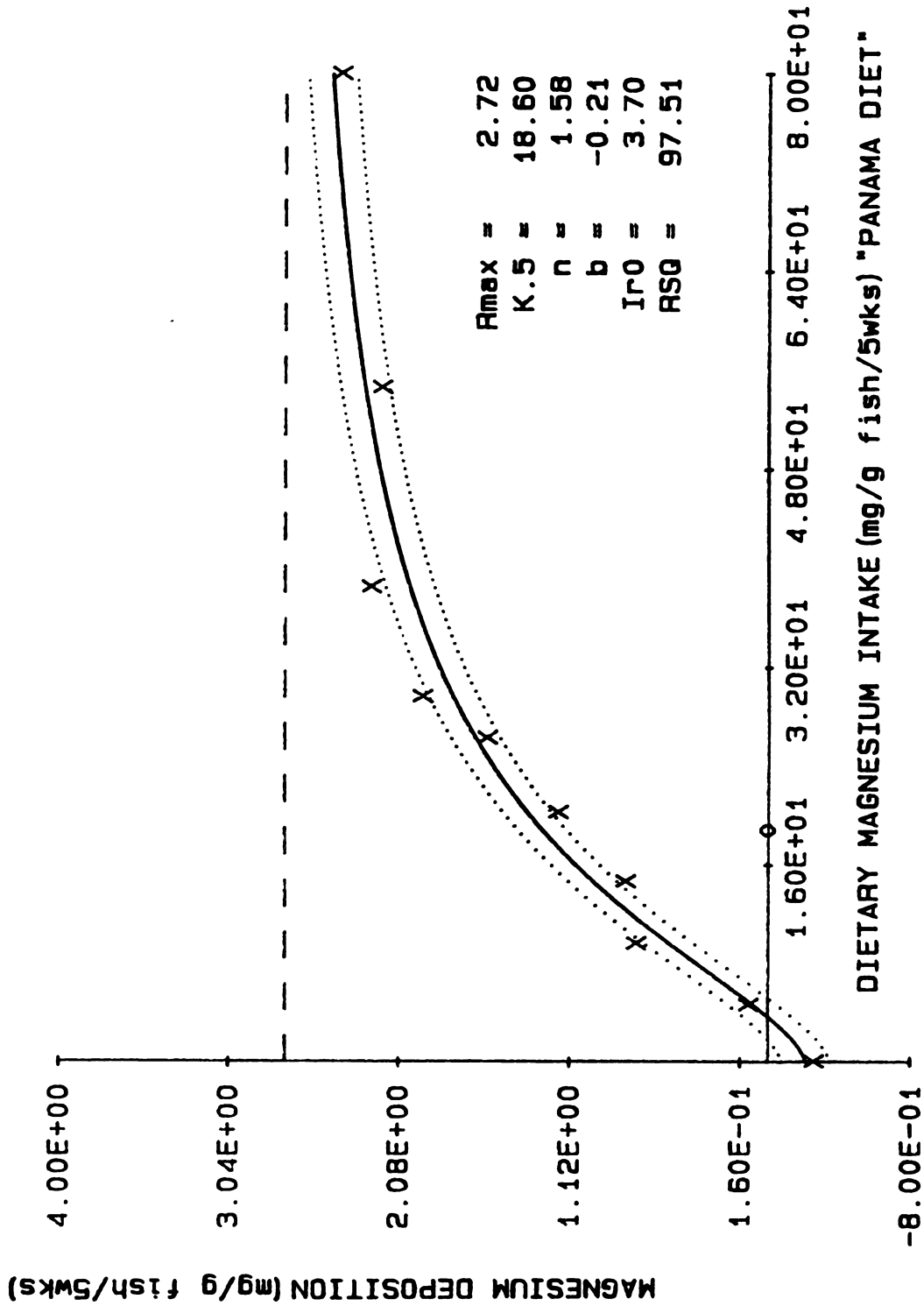


Figure 24. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of *Q. niloticus* fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

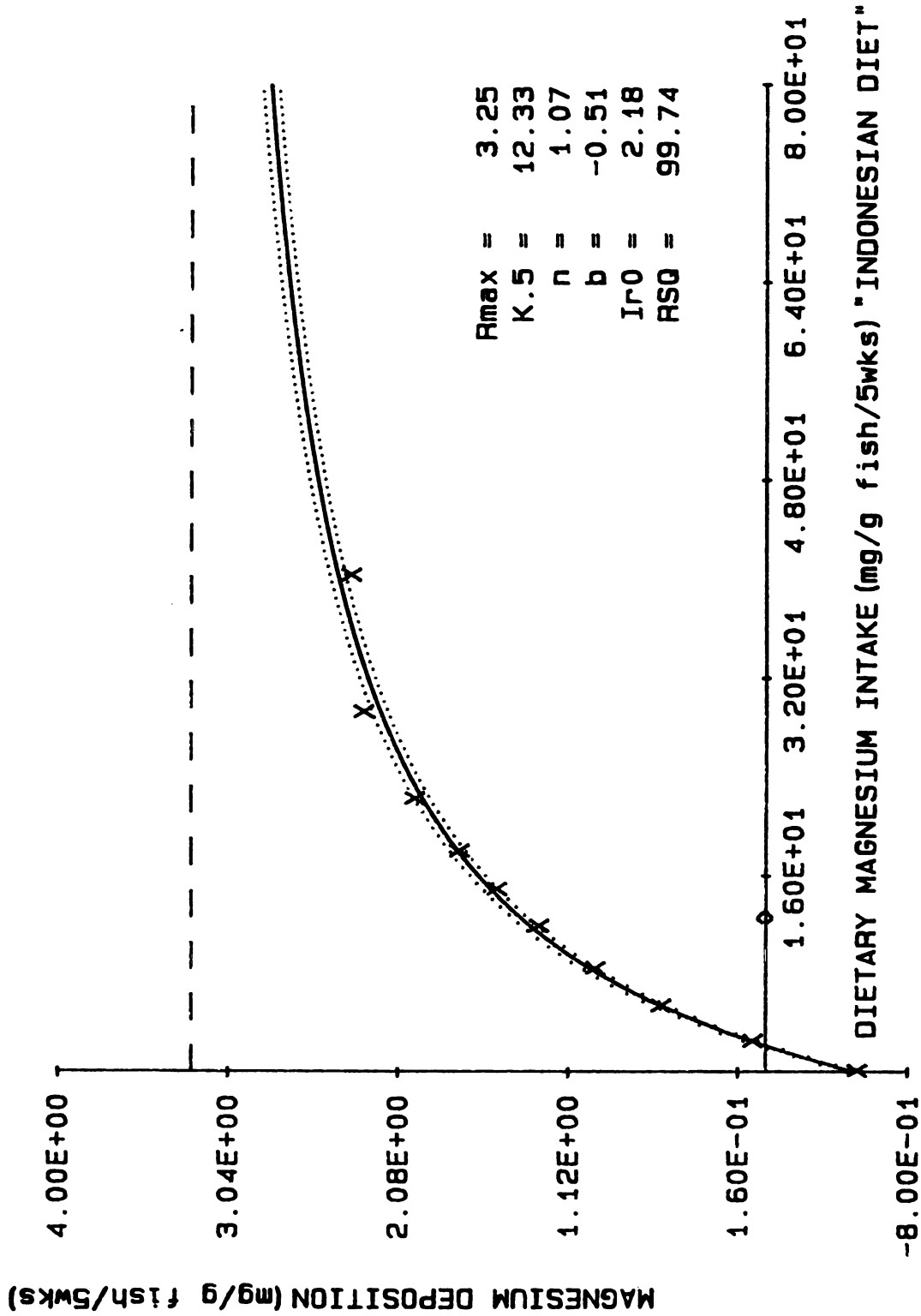


Figure 25. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of *Q. niloticus* fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

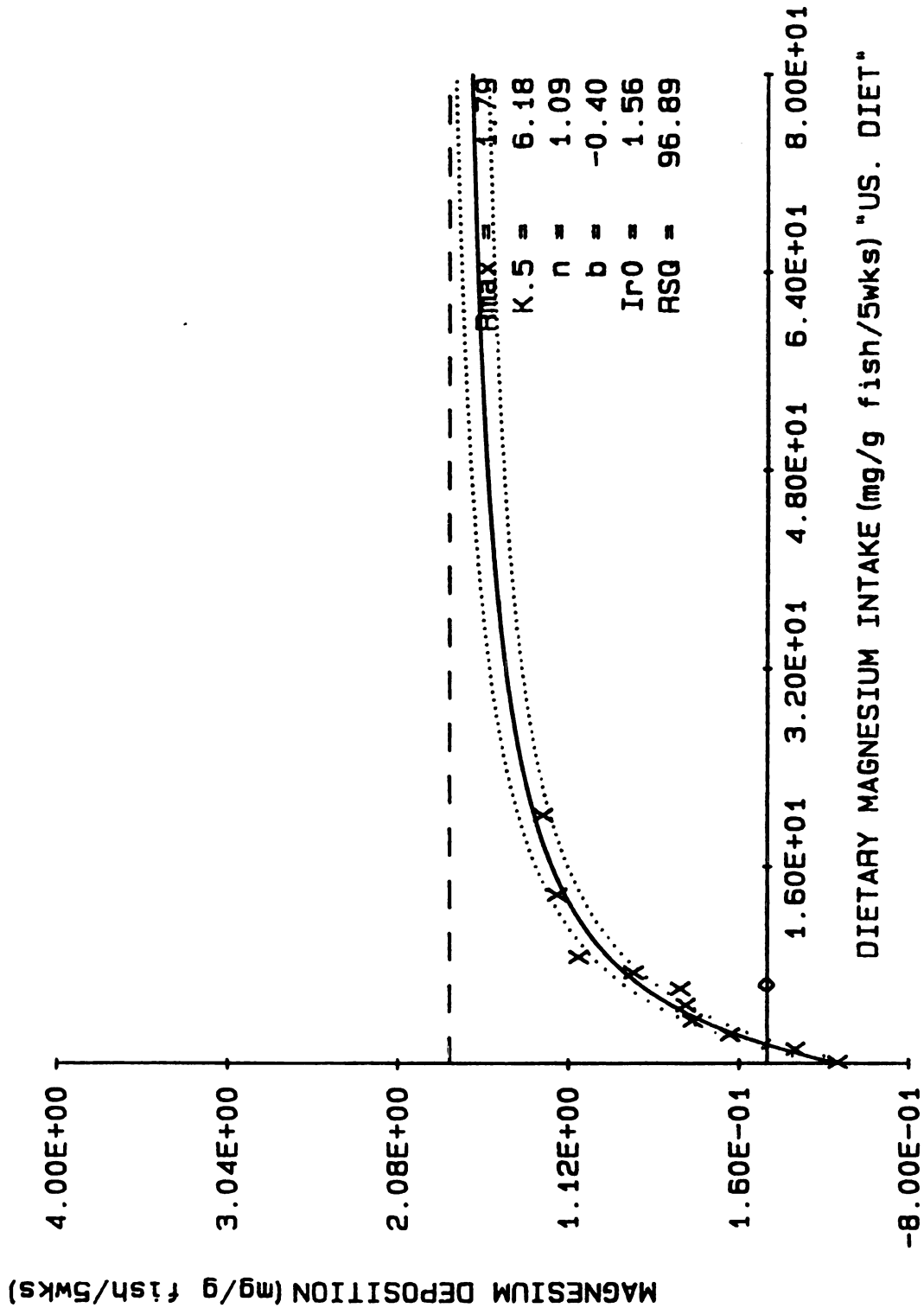


Figure 26. Theoretical nutrient response curve of magnesium intake vs magnesium deposition of *O. niloticus* fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

Table 36. Parameters derived from fitting dietary magnesium intake levels (mg/g fish initial weight/five-week) and magnesium deposition (mg/g fish/five-week period).

Source of Diet	$R_{\max}^1$	$KD_{.5}^2$	b^3	a^4	$Ir=0^5$	$\% BW^6$	$I_{\max}^7$	$\% BW^6$	$R_{\max}^8$	$R_{\max}^9$	$R_{\max.5}^{10}$
HONDURAS	$\begin{matrix} a \\ 1.52 \\ \pm .16 \end{matrix}$	$\begin{matrix} a \\ 11.61 \\ \pm 1.5 \end{matrix}$	$\begin{matrix} ab \\ -0.16 \\ \pm 0.10 \end{matrix}$	2.21	0.43	0.77	1.11	1.4	0.06	0.08	0.08
THAILAND	$\begin{matrix} b \\ 0.11 \\ \pm 0.03 \end{matrix}$	$\begin{matrix} b \\ 4.15 \\ \pm 1.18 \end{matrix}$	$\begin{matrix} b \\ 0.049 \\ \pm 0.01 \end{matrix}$	1.27	1.53	0.56	1.5	0.56	0.0008	0.02	0.018
PANAMA	$\begin{matrix} c \\ 0.27 \\ \pm 0.03 \end{matrix}$	$\begin{matrix} ab \\ 1.86 \\ \pm 0.035 \end{matrix}$	$\begin{matrix} a \\ -0.02 \\ \pm 0.002 \end{matrix}$	1.86	0.37	0.40	1.32	1.51	0.09	0.08	0.078
INDONESIA	$\begin{matrix} c \\ 0.32 \\ \pm 0.03 \end{matrix}$	$\begin{matrix} b \\ 1.23 \\ \pm 0.19 \end{matrix}$	$\begin{matrix} a \\ -0.05 \\ \pm 0.01 \end{matrix}$	1.07	0.22	0.45	0.10	0.21	-0.03	0.24	0.15
U.S.A.	$\begin{matrix} b \\ 0.17 \\ \pm 0.04 \end{matrix}$	$\begin{matrix} ab \\ 0.62 \\ \pm 0.24 \end{matrix}$	$\begin{matrix} a \\ -0.04 \\ \pm 0.01 \end{matrix}$	1.15	0.16	0.73	0.12	0.54	0.008	0.22	0.17

$1 R_{\max}$: The maximum theoretical response.

$2 KD_{.5}$: The intake level at half maximum response.

$3 b$: The response at zero intake level.

$4 a$: The kinetic order.

$5 Ir=0$: The intake at zero response (maintenance).

$6 \% BW$: Daily food intake as a percentage of body weight for the previous column.

$7 I_{\max}$: The intake at maximum efficiency.

$8 R_{\max}$: The response at maximum efficiency.

$9 R_{\max}$: Maximum efficiency.

$10 R_{\max.5}$: Overall efficiency.

maximum theoretical magnesium deposition response in fish fed the test diets was represented by $R_{\max}$ value. Fish fed the HD, PD and ID were not significantly different in terms of their $R_{\max}$ values. Fish fed the AD and HD had similar $R_{\max}$ values that were not significantly different. Fish fed the AD and TD had lower $R_{\max}$ values than those fed the PD and ID. The dietary magnesium intake (fed) that produces half $R_{\max}$ value of magnesium deposition is represented by $K0.5$. Fish fed the TD had the highest $K0.5$ value of all other test diets. Fish fed the ID had slightly better (lower) $K0.5$ values than the ones fed TD. Fish fed the ID had better $K0.5$ values than those fed the PD and were not significantly different from the ones fed the HD. Fish fed the AD had the best $K0.5$ value of all diets and were not significantly different from the ones fed the HD.

The negative magnesium deposition in fish at zero magnesium intake (b) showed no significant difference between the test diets. The kinetic order (n) showed a sigmoidal ($n > 1$) relationship.

The dietary magnesium fed (intake) that was required for maintenance (no gain or loss of body magnesium) in the test diets is represented by $I_r=0$. Fish fed the AD had the best (lowest) $I_r=0$ value of all diets, followed by fish fed the ID, PD, HD, and the TD, respectively. The maximum dietary efficiency of depositing the dietary magnesium in the fish bodies is represented by ME. The fish fed the ID had the highest ME value of all those fed other test diets.

the ME value then went down in fish fed the AD, PD and HD and TD, respectively. The dietary efficiency of depositing the dietary magnesium in the fish bodies when the fish were fed at $K_{0.5}$ level is called the overall efficiency value. Fish fed the AD had the highest overall efficiency value of all test diets. Fish fed the ID had a sharp decline in their E_{em} value and were second to those fed the AD then fish fed the HD, PD and TD, respectively.

Dietary Calcium Response

The results of dietary calcium intake (fed) and calcium deposition in the fish bodies are shown in Tables 37, 38, 39, 40, 41 and 42 and graphically in Figures 27, 28, 29, 30 and 31. A summary of the four parameters and their derivatives that was achieved by the fish in Table 42.

The maximum theoretical calcium deposition in fish fed the experimental diets were represented by R_{max} . Fish fed the ID had the highest calcium deposition R_{max} than those fed any of the other test diets. Fish fed the PD, HD, TD, and AD were not significantly different in terms of their R_{max} value for calcium deposition.

The dietary calcium intake that produced half-maximum response of calcium deposition in fish is represented by $K_{0.5}$ values. Fish fed the PD had the lowest $K_{0.5}$ value when compared to those fed any of the other test diets. Fish fed the HD, TD, and AD were not significantly

Table 37. Calcium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Honduran tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.90000	-0.85
0.5	2.0800	-0.0500	-0.22
1.0	4.4100	0.50000	0.57
1.5	6.8400	1.1800	1.31
2.0	9.3700	1.8600	1.96
2.5	10.9400	2.3300	2.31
3.0	14.9400	2.9800	3.02
3.5	17.5400	4.0100	3.40
5.0	26.6600	3.6960	4.30
7.0	40.4600	5.2400	5.04

¹Daily food intake as a percentage of the wet body weight.

²Calcium intake (mg/g fish/five weeks).

³Total calcium deposition per gram of fish wet weight during the five-week period.

⁴Calculated calcium deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 38. Calcium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Thailand tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.6000	-.053
0.5	3.4000	0.5000	-0.04
1.0	7.1000	0.7200	0.68
1.5	10.60000	1.4300	1.31
2.0	14.3000	1.7700	1.88
2.5	18.3000	2.0600	2.38
3.0	22.1000	2.5500	2.77
3.5	27.200	3.6300	3.18
5.0	32.7000	3.7300	3.52
7.0	52.8000	4.0500	4.24

¹Daily food intake as a percentage of the wet body weight.

²Calcium intake (mg/g fish/five weeks).

³Total calcium deposition per gram of fish wet weight during the five-week period.

⁴Calculated calcium deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 39. Calcium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Panamanian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-1.0000	-0.96
0.5	3.60000	0.50000	0.46
1.0	6.40000	1.77000	1.50
1.5	10.6700	2.10000	2.62
2.0	13.50000	2.9700	3.13
2.5	17.6200	3.9400	3.67
3.0	21.2500	4.2000	4.02
3.5	28.1000	4.5100	4.45
5.0	36.5100	4.8900	4.78
7.0	53.8000	4.9300	5.14

¹Daily food intake as a percentage of the wet body weight.

²Calcium intake (mg/g fish/five weeks).

³Total calcium deposition per gram of fish wet weight during the five-week period.

⁴Calculated calcium deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 40. Calcium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Indonesian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-1.4600	-1.40
0.5	7.2370	0.3100	0.22
1.0	15.6800	1.8900	1.70
1.5	24.8900	2.9200	2.92
2.0	35.2000	3.2800	3.95
2.5	44.0900	4.6100	4.65
3.0	53.3000	5.4900	5.24
3.5	66.0200	6.2200	5.89
5.0	86.9700	6.9000	6.68
7.0	119.9200	7.2000	7.51

¹Daily food intake as a percentage of the wet body weight.

²Calcium intake (mg/g fish/five weeks).

³Total calcium deposition per gram of fish wet weight during the five-week period.

⁴Calculated calcium deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 41. Calcium intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the U.S. tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-1.0000	-1.04
0.5	3.0000	-0.5000	-0.38
1.0	6.4000	0.4000	0.36
1.5	9.3000	1.0000	0.90
2.0	13.1000	1.5000	1.48
2.5	16.9000	1.8000	1.94
3.0	20.7000	2.3000	2.31
3.5	22.4000	2.6000	2.46
5.0	38.0000	2.6000	3.36
7.0	57.0000	4.0000	3.91

¹Daily food intake as a percentage of the wet body weight.

²Calcium intake (mg/g fish/five weeks).

³Total calcium deposition per gram of fish wet weight during the five-week period.

⁴Calculated calcium deposition from the saturation kinetic equation (Morgan et al. 1975).

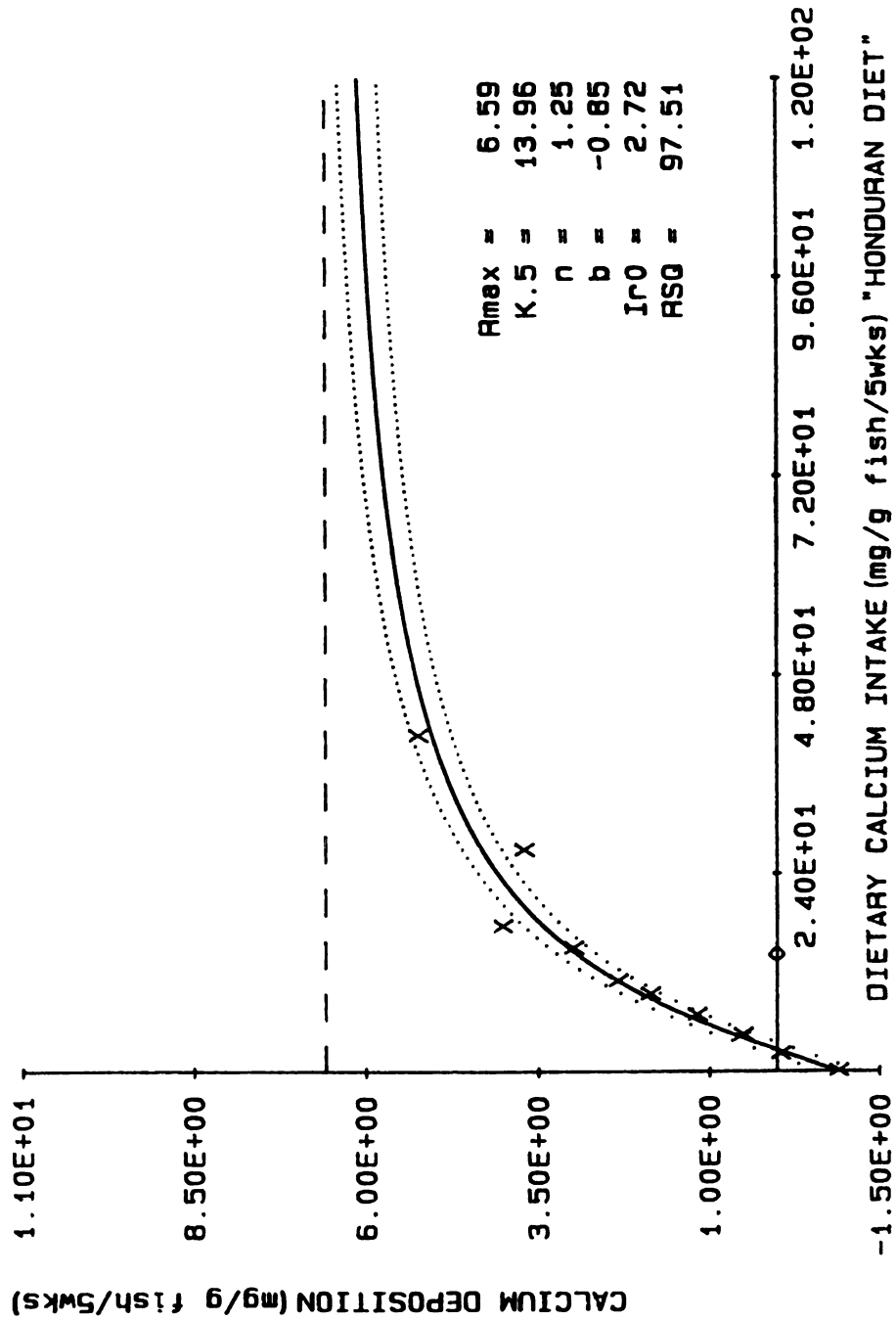


Figure 27. Theoretical nutrient response curve of calcium intake vs calcium deposition of *Q. niloticus* fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

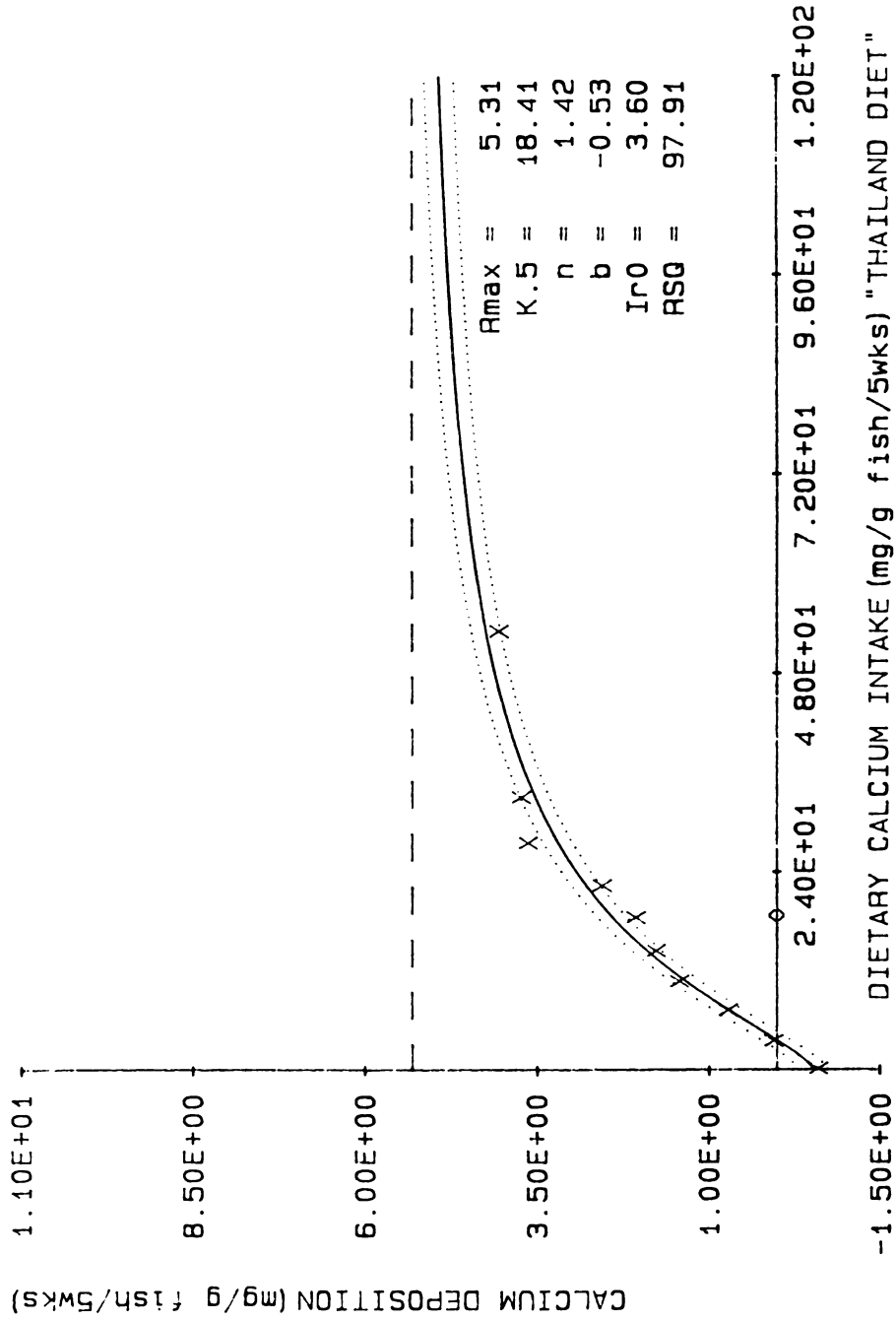


Figure 28. Theoretical nutrient response curve of calcium intake vs calcium deposition of *O. niloticus* fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

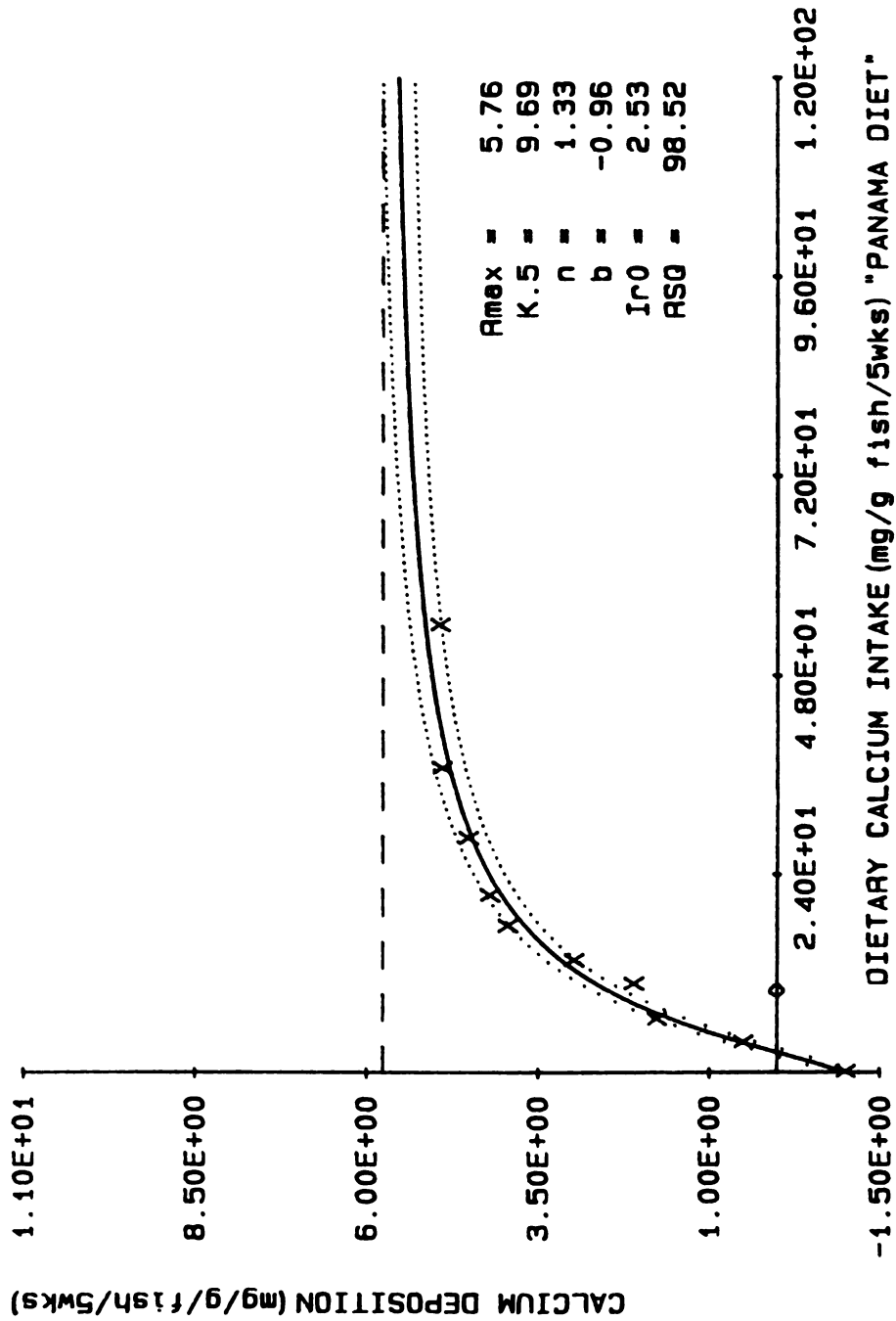


Figure 29. Theoretical nutrient response curve of calcium intake vs calcium deposition of *Q. niloticus* fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

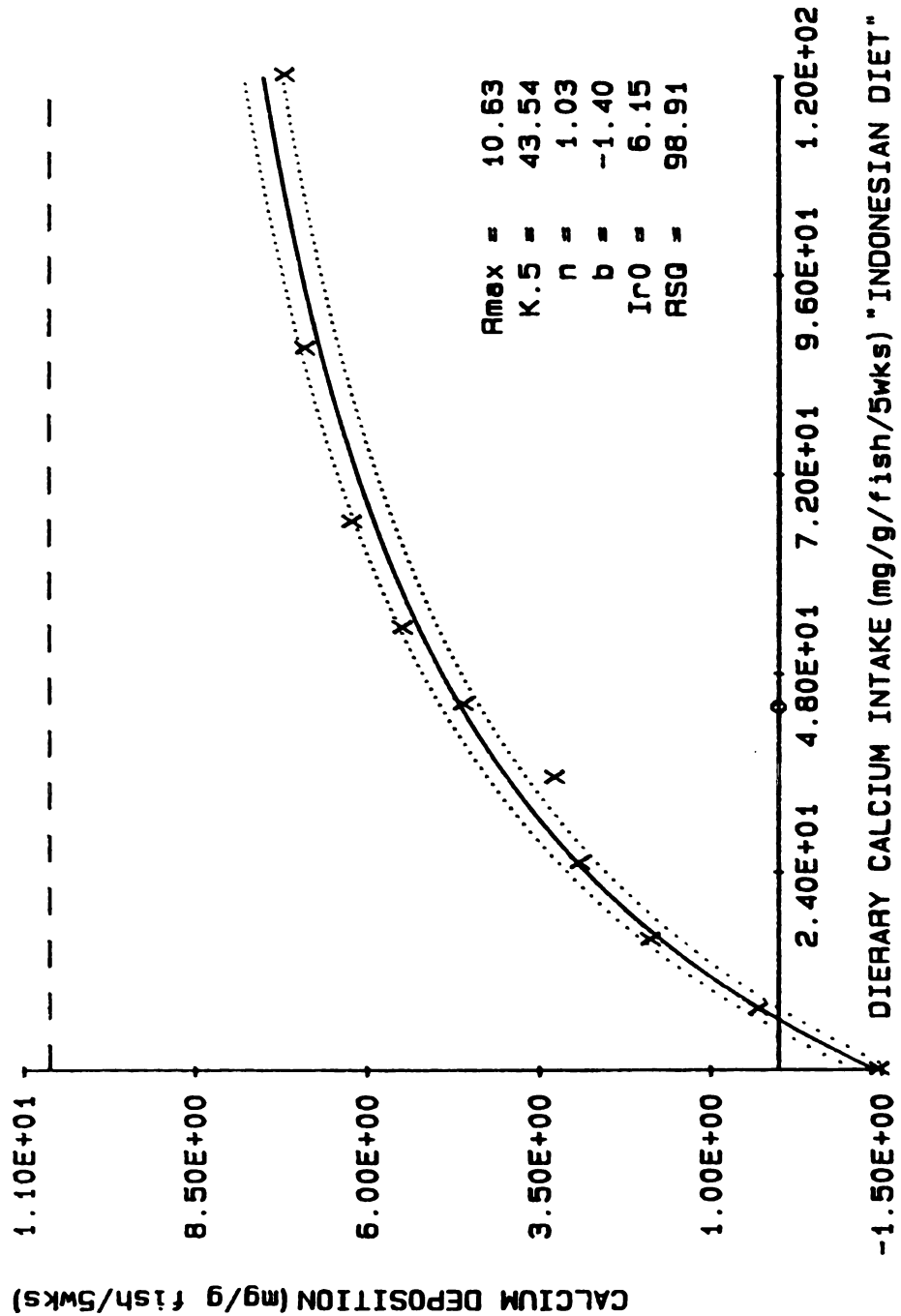


Figure 30. Theoretical nutrient response curve of calcium intake vs calcium deposition of *O. niloticus* fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

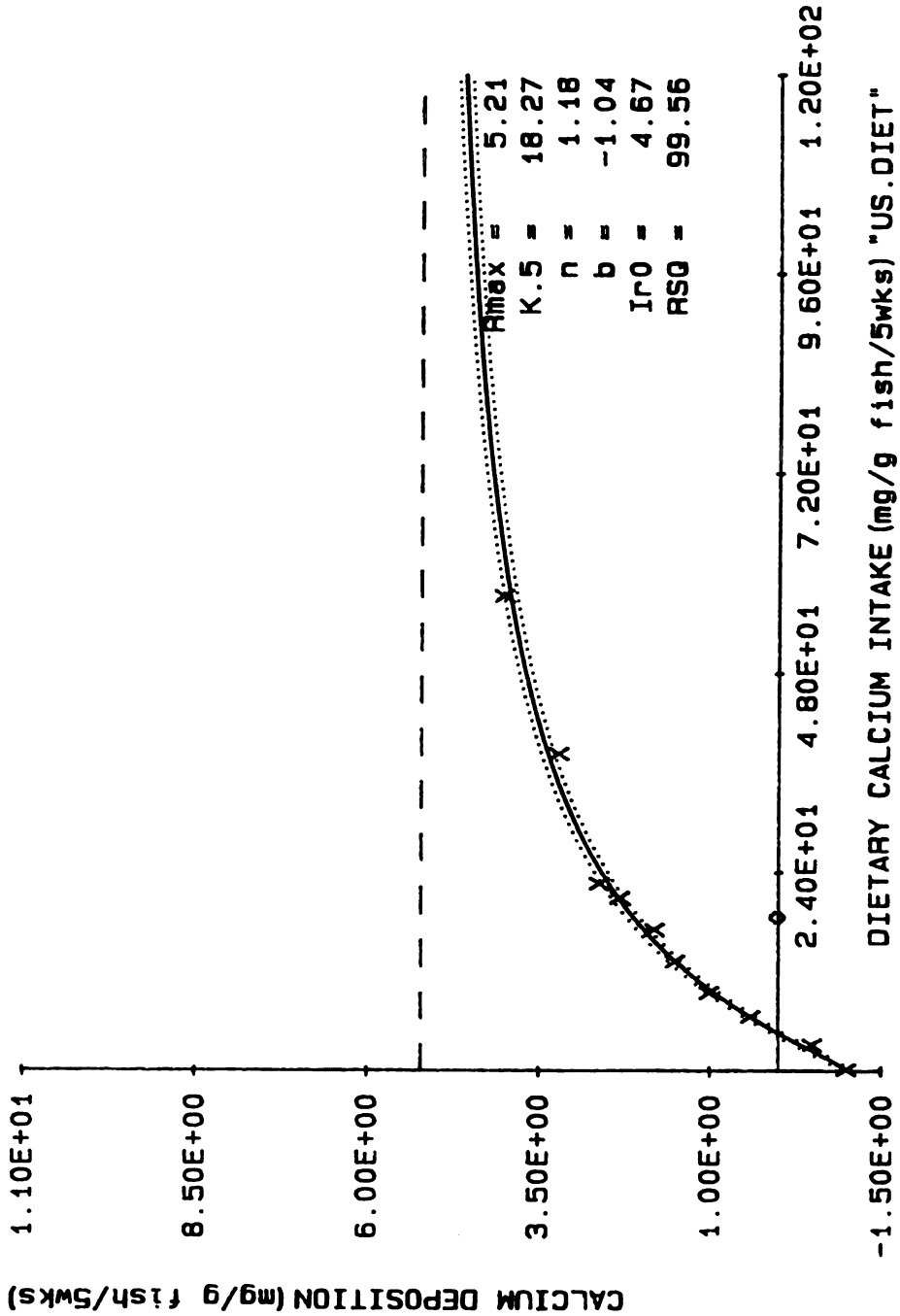


Figure 31. Theoretical nutrient response curve of calcium intake vs calcium deposition of *Q. niloticus* fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

Table 42. Parameters derived from dietary calcium levels (mg/g fish (initial weight)/five weeks) and calcium deposition (mg/g fish/five-week period).

Source of Diet	$R_{\max}^1$	$K0.5^2$	b^3	a^4	$Ir=0^5$	$\% BW^6$	I_{enz}^7	$\% BW^6$	R_{enz}^8	$R_{\max}^9$	$R_{\max.5}^{10}$
HONDURAS	a	ab	a								
	6.59 ± 1.61	13.96 ± 5.28	-0.085 ± 0.36	1.25	2.72	0.62	4.69	1.03	0.66	0.32	0.26
THAILAND	a	b	a								
	5.31 ± 1.05	18.39 ± 5.19	-0.53 ± 0.27	1.42	3.6	0.51	9.92	1.40	1.19	0.17	0.16
PANAMA	a	a	a								
	5.17 ± 0.60	9.68 ± 1.67	-0.96 ± 0.3	1.33	2.53	0.35	4.25	0.66	0.72	0.40	0.31
INDONESIA	b	c	a								
	10.63 ± 2.27	43.52 ± 16.34	-1.04 ± 0.36	1.03	6.15	0.42	1.66	0.11	-1.01	0.23	0.13
U.S.A.	a	b	a								
	5.21 ± 0.54	18.27 ± 2.93	-1.04 ± 0.12	1.18	4.67	0.73	4.23	0.66	0.096	0.22	0.17

¹ $R_{\max}$: The maximum theoretical response.² $K0.5$: The intake level at half maximum response.³ b : The response at zero intake level.⁴ a : The kinetic order.⁵ $Ir=0$: The intake at zero response (maintenance).⁶ $\% BW$: Daily food intake as a percentage of body weight for the previous column.⁷ I_{enz} : The intake at maximum efficiency.⁸ R_{enz} : The response at maximum efficiency.⁹ $R_{\max}$: Maximum efficiency.¹⁰ $R_{\max.5}$: Overall efficiency.

different in terms of their $K_{0.5}$ values. Fish fed the ID had a significantly higher $K_{0.5}$ value than those fed any of the other test diets.

At zero calcium intake level (b) there was no significant difference between fish fed various test diets in the negative calcium deposition. The kinetic order (n) shows a sigmoidal ($n > 1$) curve relationship in calcium intake and deposition in O. niloticus.

The amount of calcium fed to maintain zero calcium deposition in fish is represented by $I_r=0$. The fish fed the PD had the best $I_r=0$ value of all those fed the other test diets, then, fish fed the HD, TD, AD, and ID had higher $I_r=0$ values, respectively. The maximum amount of calcium deposited in the fish bodies with the smallest amount of dietary calcium intake is defined as the maximum efficiency (E_{mx}). Fish fed the PD had the highest E_{mx} value of all those fed the other test diets. The ME value decreased as the fish fed the HD, ID, AD and TD, respectively. The dietary calcium efficiency at $K_{0.5}$ value is represented by the overall efficiency value. There was a sharp decrease in the dietary efficiency when the E_{mx} values were compared to the overall efficiency value of fish fed the PD and ID. Fish fed the PD had the best overall efficiency value when compared to all others fed the other test diets. Fish fed the Honduran diet had a lower overall efficiency value than those fed the PD. The efficiency values declined in the fish fed the AD, TD, and ID, respectively.

Dietary Zinc Response

The results of dietary zinc intake and zinc deposition in fish (mgr/g fish/five-week period) are shown in Tables 43, 44, 45, 46, and 47. The above information is also shown graphically in Figures 33, 33, 34, 35, and 36. A summary of the four parameters and their derivatives that are achieved by the fish are shown in Table 48.

The maximum theoretical zinc deposition in fish fed any of the test diets is represented by $R_{\max}$. Fish fed the ID had more than twice the $R_{\max}$ value of those fed the other test diets. Fish fed the PD, TD, and AD were not significantly different in terms of their $R_{\max}$ values. Fish fed the HD had a lower $R_{\max}$ value than those fed the PD and were not significantly different from fish fed the TD or AD.

The dietary zinc intake that produces half $R_{\max}$ of zinc deposition in fish is represented by $K0.5$. Fish fed the ID had higher $K0.5$ values than those fed any of the other test diets. Fish fed the AD, PD and TD were not significantly different in terms of their $K0.5$ values. Fish fed the HD had the least $K0.5$ value of all those fed the other test diets. At zero dietary zinc intake there were no significant differences in terms of fish body zinc negative accumulations (b). The kinetic order (n) showed a sigmoidal ($n > 1$) relationship between dietary zinc intake and deposition in the fish bodies.

Table 43. Zinc intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Honduran tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-2.8000	-2.83
0.5	7.8000	-0.3000	-0.25
1.0	16.4000	2.4000	2.41
1.5	21.9000	3.6000	3.65
2.0	35.0000	5.9000	5.61
2.5	41.6000	6.3000	6.26
3.0	56.0000	7.0000	7.22
3.5	66.0000	7.7000	7.67
5.0	100.0000	8.2000	8.54
7.0	151.0000	9.4000	9.10

¹Daily food intake as a percentage of the wet body weight.

²Zinc intake (mg/g fish/five weeks).

³Total dietary zinc deposition per gram of fish wet weight during the five-week period.

⁴Calculated zinc deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 44. Zinc intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Thailand tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-3.6000	-3.45
0.5	11.0000	0.1400	-0.46
1.0	23.0000	1.6100	1.99
1.5	35.0000	3.2200	3.70
2.0	47.0000	5.0800	4.93
2.5	58.0000	5.5600	5.78
3.0	72.0000	6.3800	6.61
3.5	89.0000	8.3000	7.36
5.0	125.0000	8.9000	8.40
7.0	173.0000	8.4500	9.20

¹Daily food intake as a percentage of the wet body weight.

²Zinc intake (mg/g fish/five weeks).

³Total dietary zinc deposition per gram of fish wet weight during the five-week period.

⁴Calculated zinc deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 45. Zinc intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Panamanian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-2.300	-1.98
0.5	18.0000	0.8300	0.27
1.0	38.0000	4.1700	3.77
1.5	58.0000	5.1600	6.33
2.0	80.0000	6.7600	8.11
2.5	104.0000	10.1600	9.30
3.0	117.0000	11.7200	9.74
3.5	152.0000	10.6900	10.53
5.0	216.0000	10.7000	11.24
7.0	316.0000	11.1100	11.69

¹Daily food intake as a percentage of the wet body weight.

²Zinc intake (mg/g fish/five weeks).

³Total dietary zinc deposition per gram of fish wet weight during the five-week period.

⁴Calculated zinc deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 46. Zinc intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Indonesian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-3.240	-3.15
0.5	21.0000	0.7100	0.66
1.0	45.0000	4.7500	4.07
1.5	72.0000	6.4000	6.99
2.0	101.0000	9.1200	9.46
2.5	127.0000	10.4400	11.10
3.0	153.0000	12.6400	12.49
3.5	190.0000	14.7300	14.08
5.0	250.0000	16.8000	15.99
7.0	345.0000	17.3000	18.03

¹Daily food intake as a percentage of the wet body weight.

²Zinc intake (mg/g fish/five weeks).

³Total dietary zinc deposition per gram of fish wet weight during the five-week period.

⁴Calculated zinc deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 47. Zinc intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the U.S. tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-2.7000	-2.74
0.5	8.0000	-1.2300	-1.20
1.0	17.0000	0.8000	0.91
1.5	26.0000	2.4000	2.67
2.0	35.0000	4.9000	4.04
2.5	46.0000	5.1000	5.28
3.0	57.0000	5.7000	6.19
3.5	66.0000	6.4000	6.76
5.0	103.0000	8.7500	8.17
7.0	153.0000	8.900	9.03

¹Daily food intake as a percentage of the wet body weight.

²Zinc intake (mg/g fish/five weeks).

³Total dietary zinc deposition per gram of fish wet weight during the five-week period.

⁴Calculated zinc deposition from the saturation kinetic equation (Morgan et al. 1975).

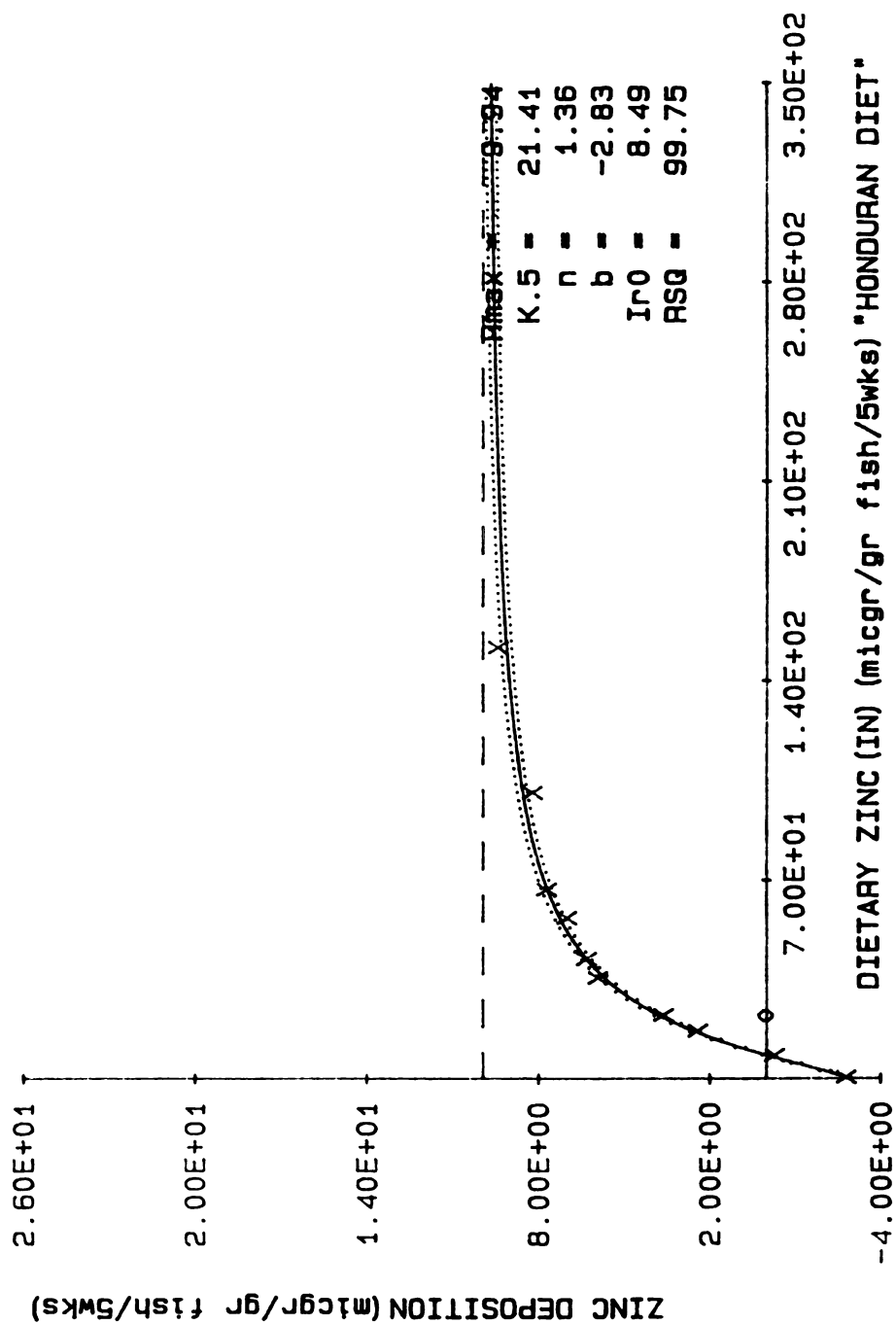


Figure 32. Theoretical nutrient response curve of zinc intake vs zinc deposition of *Q. niloticus* fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

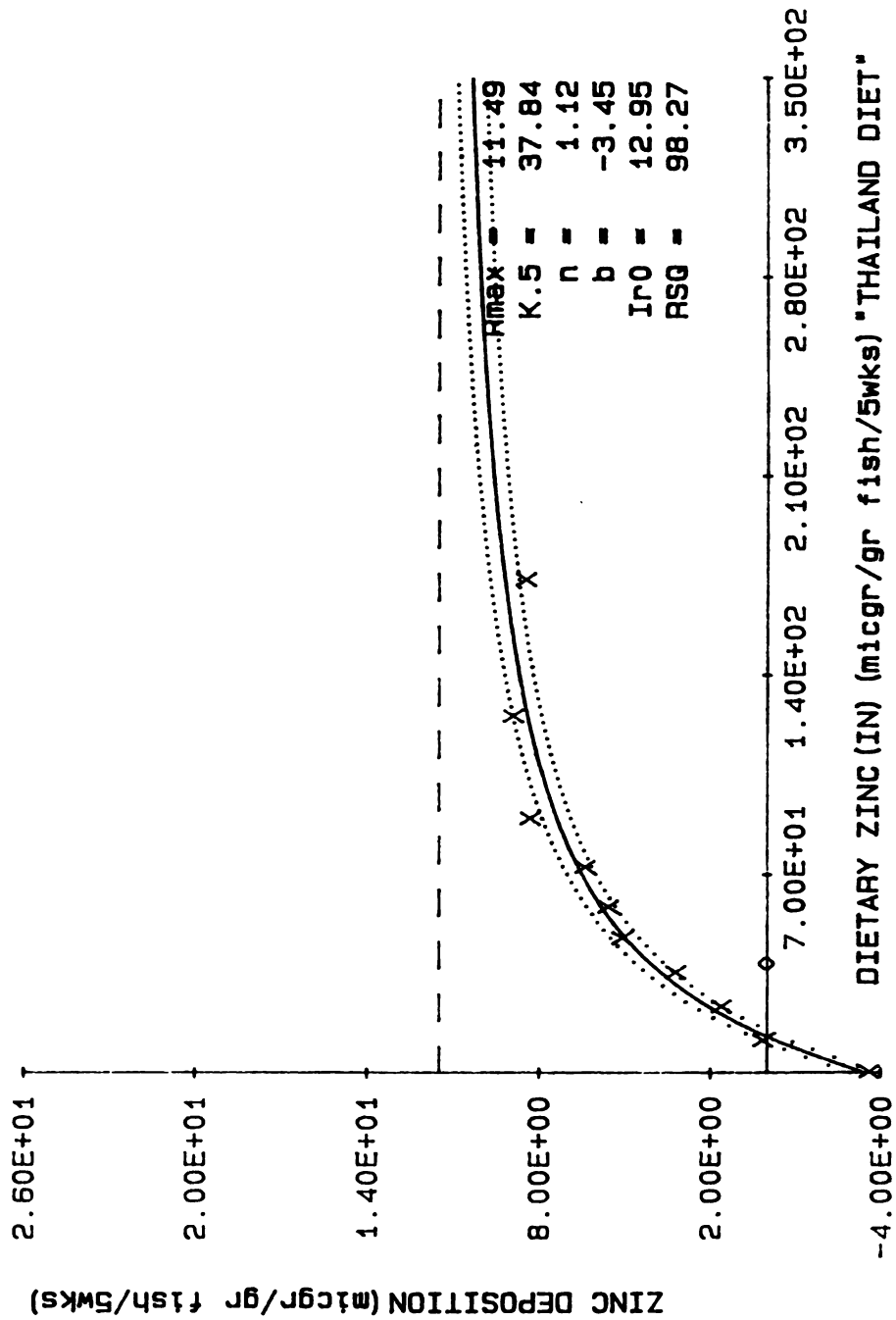


Figure 33. Theoretical nutrient response curve of zinc intake vs zinc deposition of *Q. niloticus* fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, n=3).

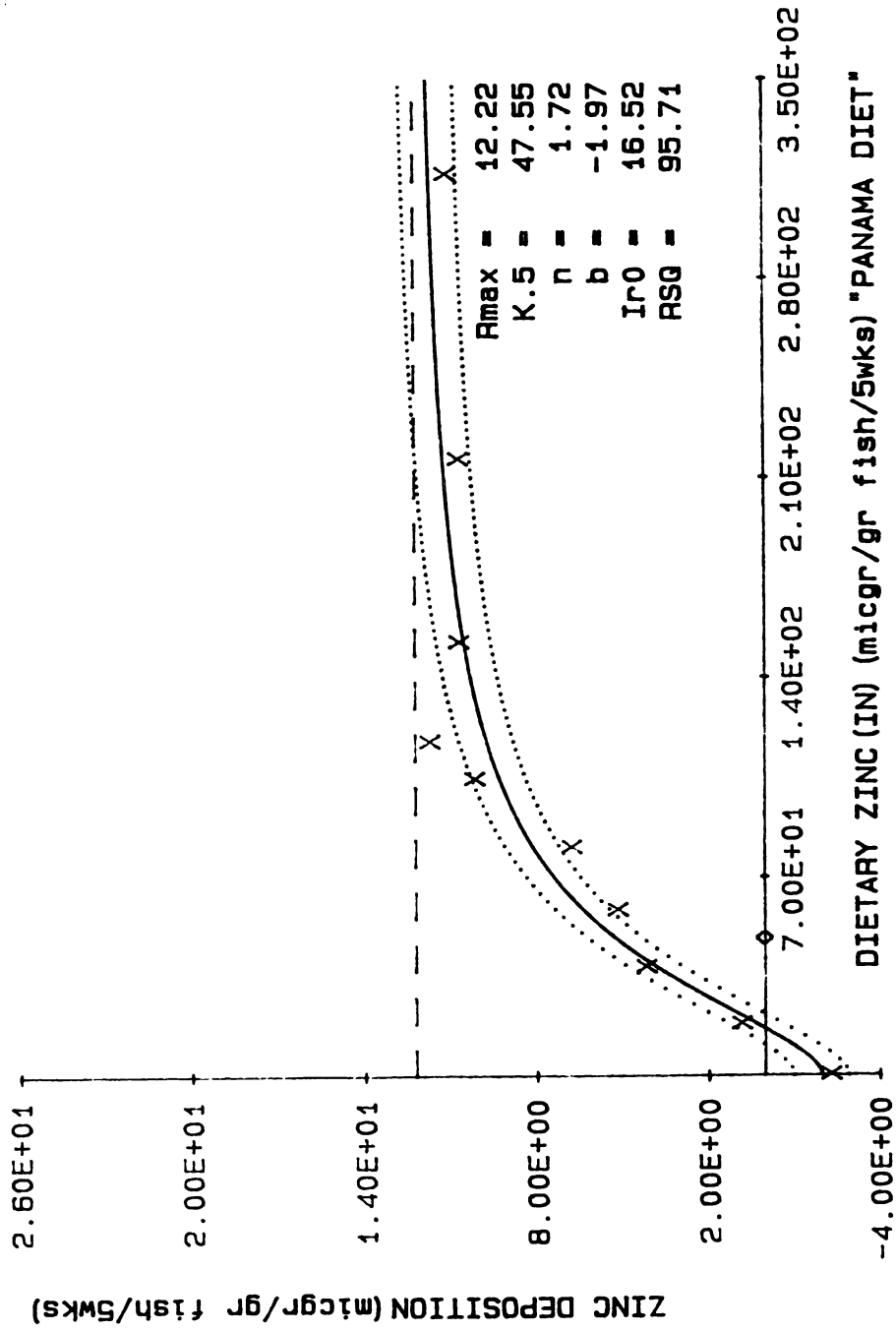


Figure 34. Theoretical nutrient response curve of zinc intake vs zinc deposition of *O. niloticus* fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

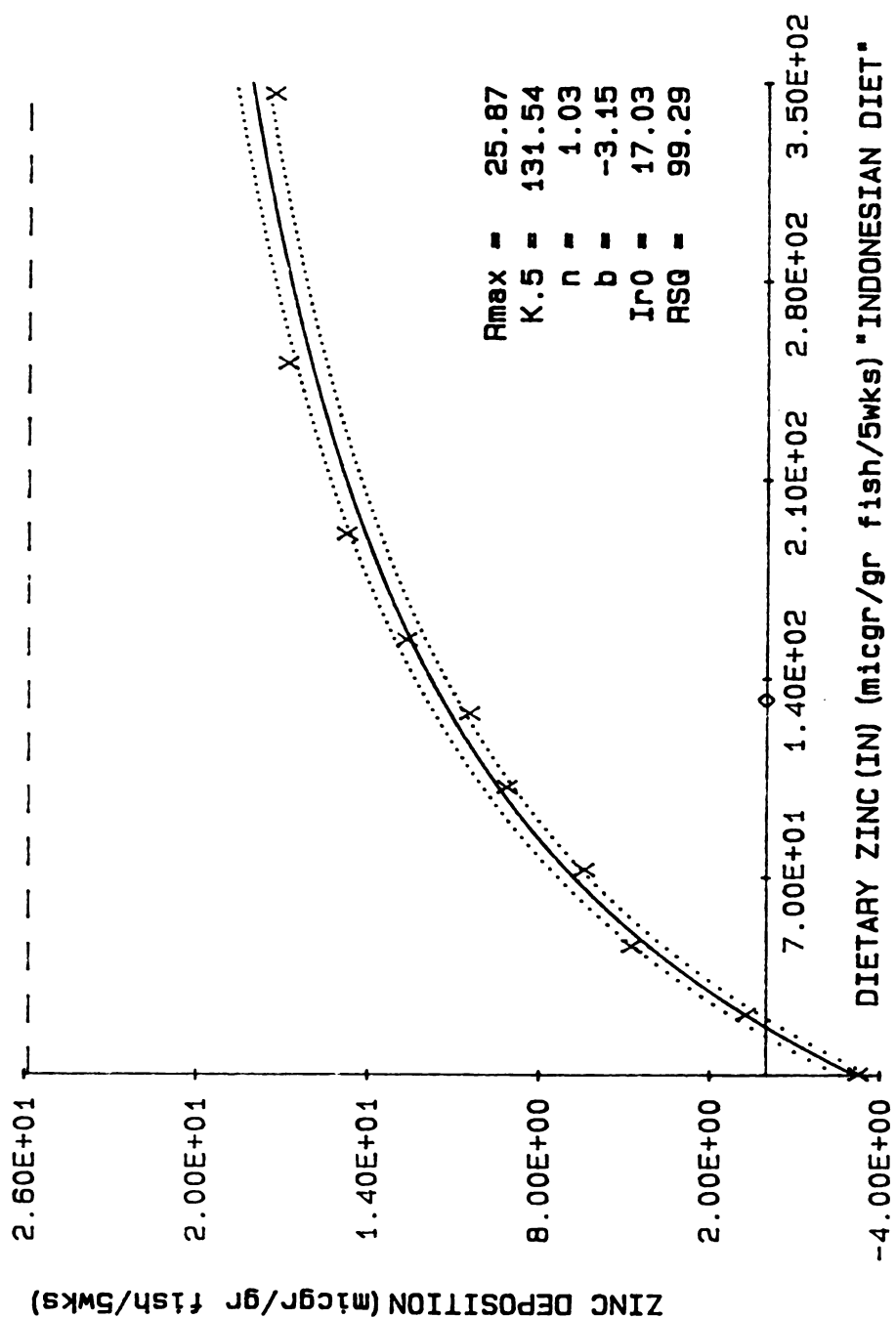


Figure 35. Theoretical nutrient response curve of zinc intake vs zinc deposition of *Q. niloticus* fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

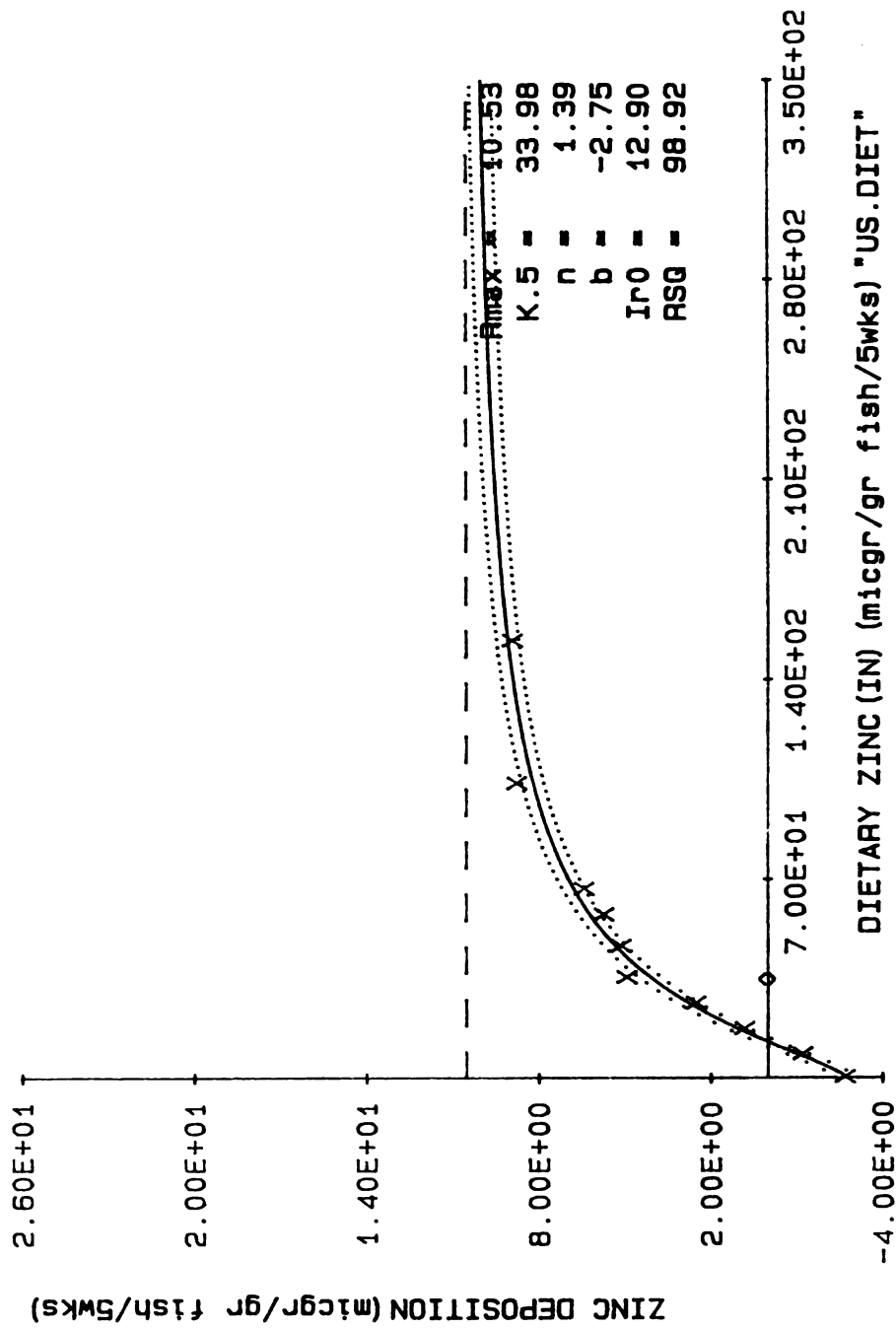


Figure 36. Theoretical nutrient response curve of zinc intake vs zinc deposition of *O. niloticus* fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

Table 48. Parameters derived from fitting dietary zinc intake levels ($\mu\text{gr/g}$ fish initial weight/five weeks) and zinc deposition ($\mu\text{g/g}$ fish/five week-period).

Source of Diet	R_{max}^1	$K_{0.5}^2$	b^3	a^4	$\text{Ir}=0^5$	$\% BW^6$	I_{enz}^7	$\% BW^6$	R_{enz}^8	R_{max}^9	$R_{\text{max}.5}^{10}$
HONDURAS	9.94 ± 0.38	21.14 ± 1.33	-2.83 ± 0.24	a	8.49	0.52	10.1	0.62	0.55	0.33	0.30
THAILAND	11.49 ± 2.06	37.81 ± 10.77	-3.45 ± 0.65	a	12.95	0.56	5.85	0.27	-1.81	0.28	0.20
PANAMA	12.21 ± 1.45	47.49 ± 9.73	-1.98 ± 1.19	a	16.52	0.46	39.4	1.02	3.98	0.15	0.14
INDONESIA	25.87 ± 4.35	131.55 ± 40.94	-3.15 ± 0.69	a	17.03	0.41	4.46	0.11	-0.02	0.19	0.11
U.S.A.	10.43 ± 1.13	33.57 ± 4.98	-2.74 ± 0.44	a	13.0	0.76	17.76	1.02	1.07	0.21	0.19

¹ R_{max} : The maximum theoretical response.

² $K_{0.5}$: The intake level at half maximum response.

³ b : The response at zero intake level.

⁴ a : The kinetic order.

⁵ $\text{Ir}=0$: The intake at zero response (maintenance).

⁶ $\% BW$: Daily food intake as a percentage of body weight for the previous column.

⁷ I_{enz} : The intake at maximum efficiency.

⁸ R_{enz} : The response at maximum efficiency.

⁹ R_{max} : Maximum efficiency.

¹⁰ $R_{\text{max}.5}$: Overall efficiency.

The dietary zinc fed that maintain body zinc levels at maintenance (no gain or loss) is represented by $I_r=0$ values for each diet. Fish fed the HD were the most efficient (had the lowest $I_r=0$ value), followed by those fed the TD, AD, PD and the ID, respectively. The dietary maximum efficiency of depositing the dietary zinc in the fish is represented by $E_{\max}$. Fish fed the HD had the highest $E_{\max}$ value of all those fed the other test diets, followed by those fed the TD, AD, ID and PD, respectively. The dietary zinc efficiency when the experimental fish fed at the $K_{0.5}$ level of each diet is represented by the overall efficiency values. Fish fed the HD were the most efficient in terms of their overall efficiency value followed by those fed the TD, AD, PD and TD, respectively.

Dietary Phosphorus Response

The dietary phosphorus deposited in the fish bodies as a function of dietary phosphorus intake (fed) each of the experimental tilapia diet are shown in Tables 49, 50, 51, 52, and 53. The same information is shown graphically in Figures 37, 38, 39, 40 and 41. A summary of the four parameters and their derivatives that are achieved by the fish are shown in Table 54.

The maximum amount of dietary phosphorus that was deposited in the fish fed each of the experimental diets was represented by $R_{\max}$ values. Fish fed the PD had the highest $R_{\max}$ value of all those fed test feeds. Fish fed the ID had the higher $R_{\max}$ value than those fed

Table 49. Phosphorus intake, observed deposition (ro), and calculated deposition (rc) of O. niloticus fed varying percentages of the Honduran tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-1.3650	-1.45
0.5	3.8500	-0.8400	-0.58
1.0	8.2250	0.9800	0.54
1.5	12.7400	1.0850	1.14
2.0	17.4650	1.2600	1.45
2.5	20.4050	1.3300	1.56
3.0	27.7550	1.3300	1.22
3.5	32.6900	1.9600	1.78
5.0	35.3500	1.9950	1.80
7.0	40.5900	2.0650	1.83

¹Daily food intake as a percentage of the wet body weight.

²Phosphorus intake (mg/g fish/five weeks).

³Total dietary phosphorus deposition per gram of fish wet weight during the five-week period.

⁴Calculated phosphorus deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 50. Phosphorus intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Thailand tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-1.6800	-1.62
0.5	3.7000	0.0770	-0.17
1.0	7.8050	0.8050	1.02
1.5	11.6500	1.5750	1.77
2.0	14.5600	2.2400	2.19
2.5	20.0900	2.6600	2.75
3.0	24.3950	3.2900	3.06
3.5	29.8900	3.6050	3.36
5.0	42.0350	3.7100	3.77
7.0	58.1000	3.9200	4.08

¹Daily food intake as a percentage of the wet body weight.

²Phosphorus intake (mg/g fish/five weeks).

³Total dietary phosphorus deposition per gram of fish wet weight during the five-week period.

⁴Calculated phosphorus deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 51. Phosphorus intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Panamanian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-1.3650	-0.78
0.5	2.2750	0.4200	-0.39
1.0	4.9000	0.9800	1.03
1.5	7.2450	2.0650	2.55
2.0	10.0450	4.4100	4.05
2.5	13.0500	4.4450	5.17
3.0	14.7000	5.600	5.60
3.5	15.4000	6.7900	5.75
5.0	27.0550	6.5450	6.94
7.0	39.6550	7.5150	7.28

¹Daily food intake as a percentage of the wet body weight.

²Phosphorus intake (mg/g fish/five weeks).

³Total dietary phosphorus deposition per gram of fish wet weight during the five-week period.

⁴Calculated phosphorus deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 52. Phosphorus intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the Indonesian tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-1.2600	-1.20
0.5	2.3500	0.1960	0.04
1.0	5.1000	1.5400	1.57
1.5	8.1000	2.7300	2.85
2.0	11.4500	3.7100	3.85
2.5	14.500	4.5500	4.51
3.0	17.3300	5.1450	4.96
3.5	21.4700	5.4950	5.45
5.0	28.2800	6.0900	5.99
7.0	39.0000	6.3000	6.47

¹Daily food intake as a percentage of the wet body weight.

²Phosphorus intake (mg/g fish/five weeks).

³Total dietary phosphorus deposition per gram of fish wet weight during the five-week period.

⁴Calculated phosphorus deposition from the saturation kinetic equation (Morgan et al. 1975).

Table 53. Phosphorus intake, observed deposition (ro), and calculated deposition (rc) of *O. niloticus* fed varying percentages of the U.S. tilapia feed.

% BW ¹	Intake ²	ro ³	rc ⁴
0	0.0000	-0.7700	-0.79
0.5	1.5300	-0.3150	-0.20
1.0	3.2400	0.4200	0.31
1.5	4.8900	0.8050	0.69
2.0	6.6600	1.1550	1.02
2.5	8.5500	1.0500	1.29
3.0	9.9000	1.1600	1.44
3.5	12.3450	1.7850	1.68
5.0	19.3350	2.2150	2.12
7.0	28.7550	2.2100	2.45

¹Daily food intake as a percentage of the wet body weight.

²Phosphorus intake (mg/g fish/five weeks).

³Total dietary phosphorus deposition per gram of fish wet weight during the five-week period.

⁴Calculated phosphorus deposition from the saturation kinetic equation (Morgan et al. 1975).

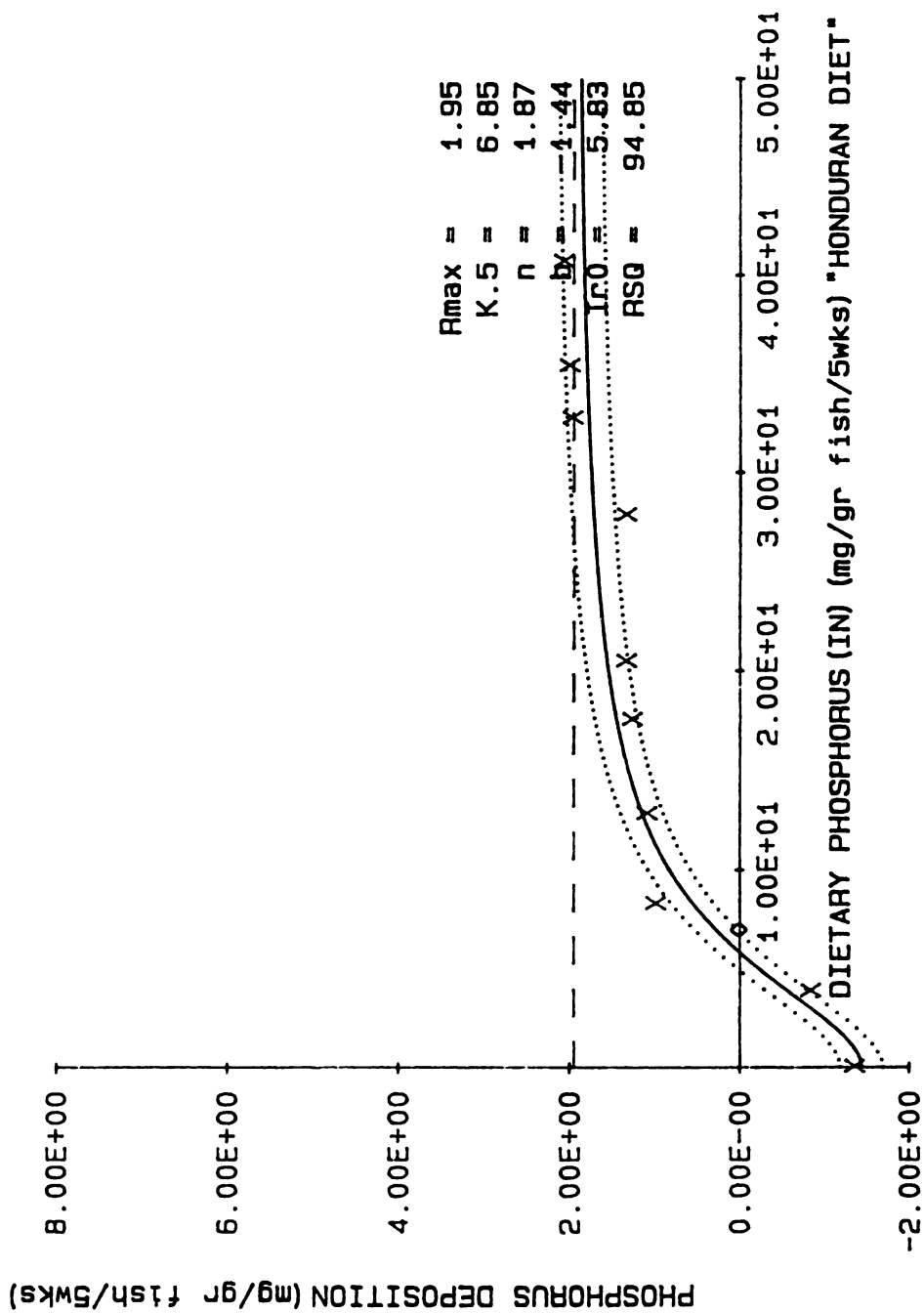


Figure 37. Theoretical nutrient response curve of phosphorus intake vs. phosphorus deposition of *O. niloticus* fed the Honduran diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

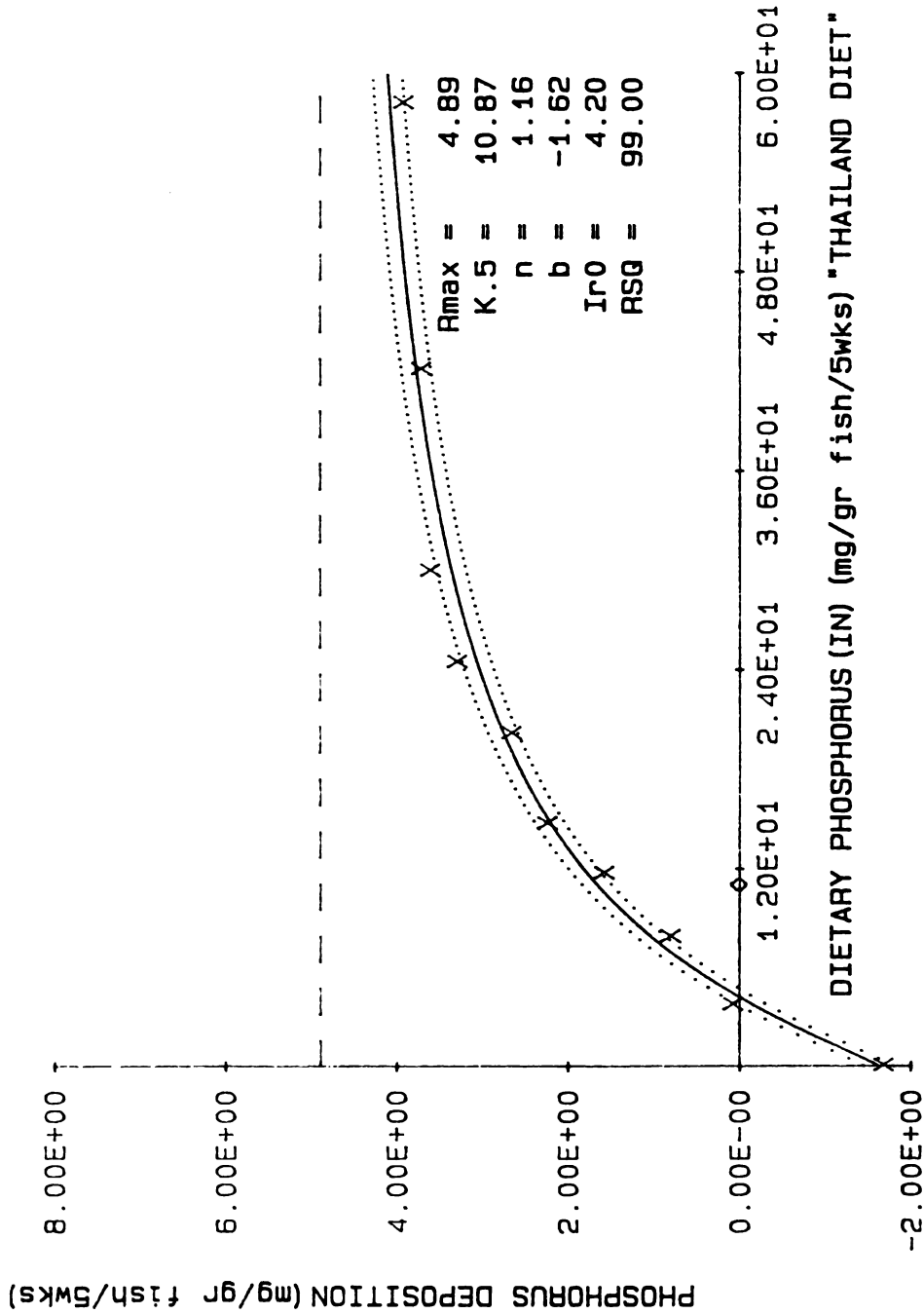


Figure 38. Theoretical nutrient response curve of phosphorus intake vs. phosphorus deposition of *O. niloticus* fed the Thailand diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

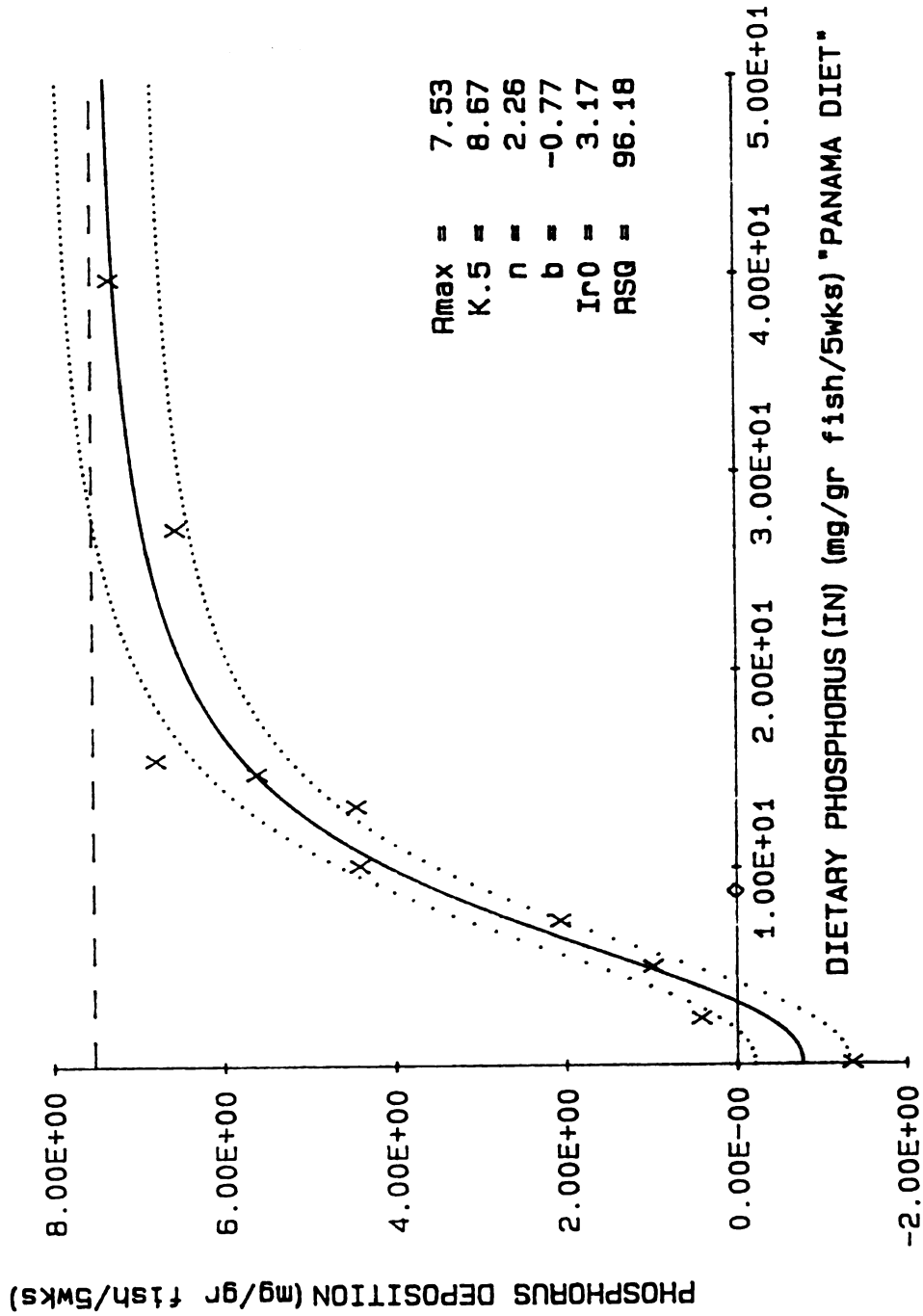


Figure 39. Theoretical nutrient response curve of phosphorus intake vs. phosphorus deposition of *O. niloticus* fed the Panamanian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

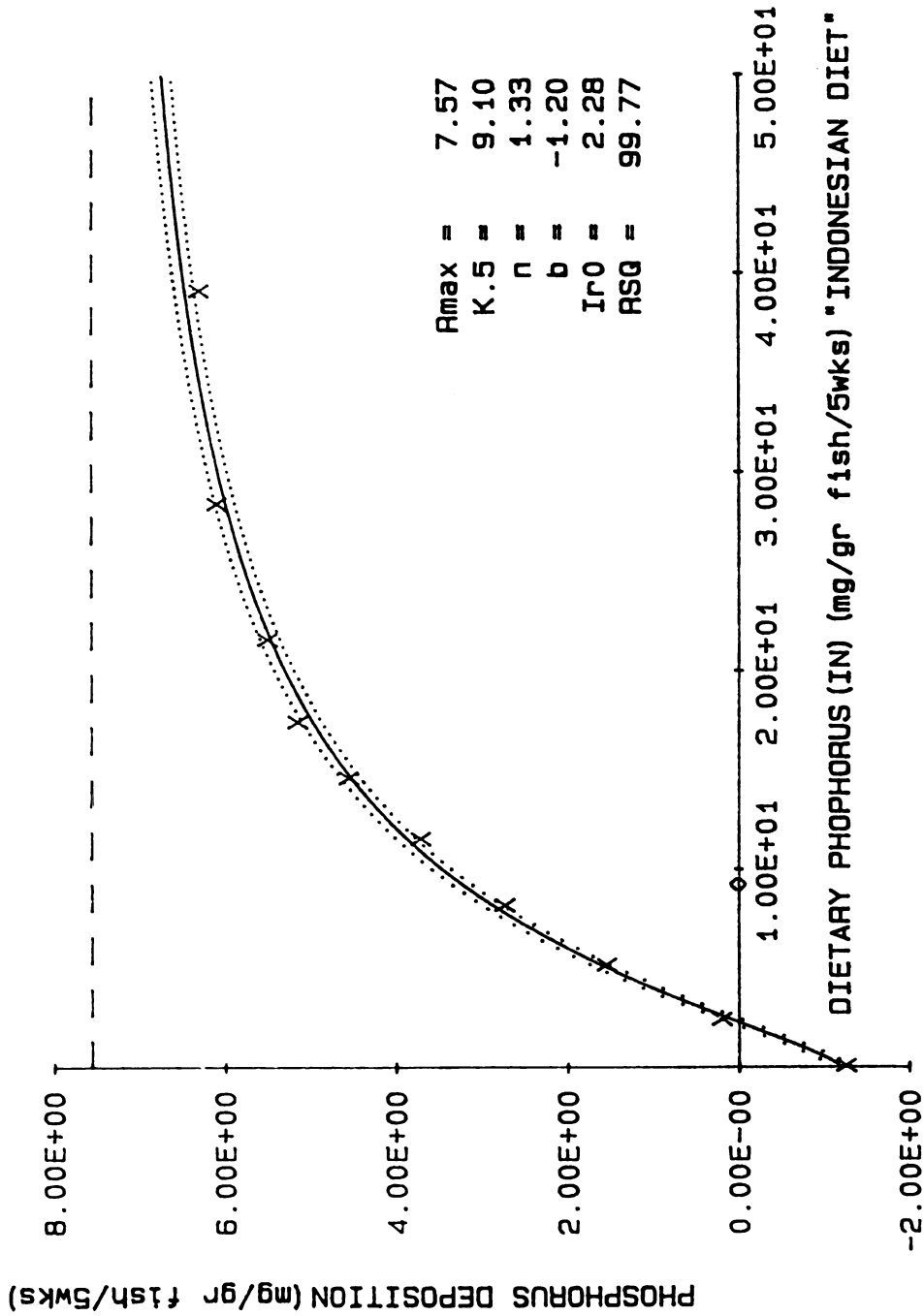


Figure 40. Theoretical nutrient response curve of phosphorus intake vs. phosphorus deposition of *Q. niloticus* fed the Indonesian diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

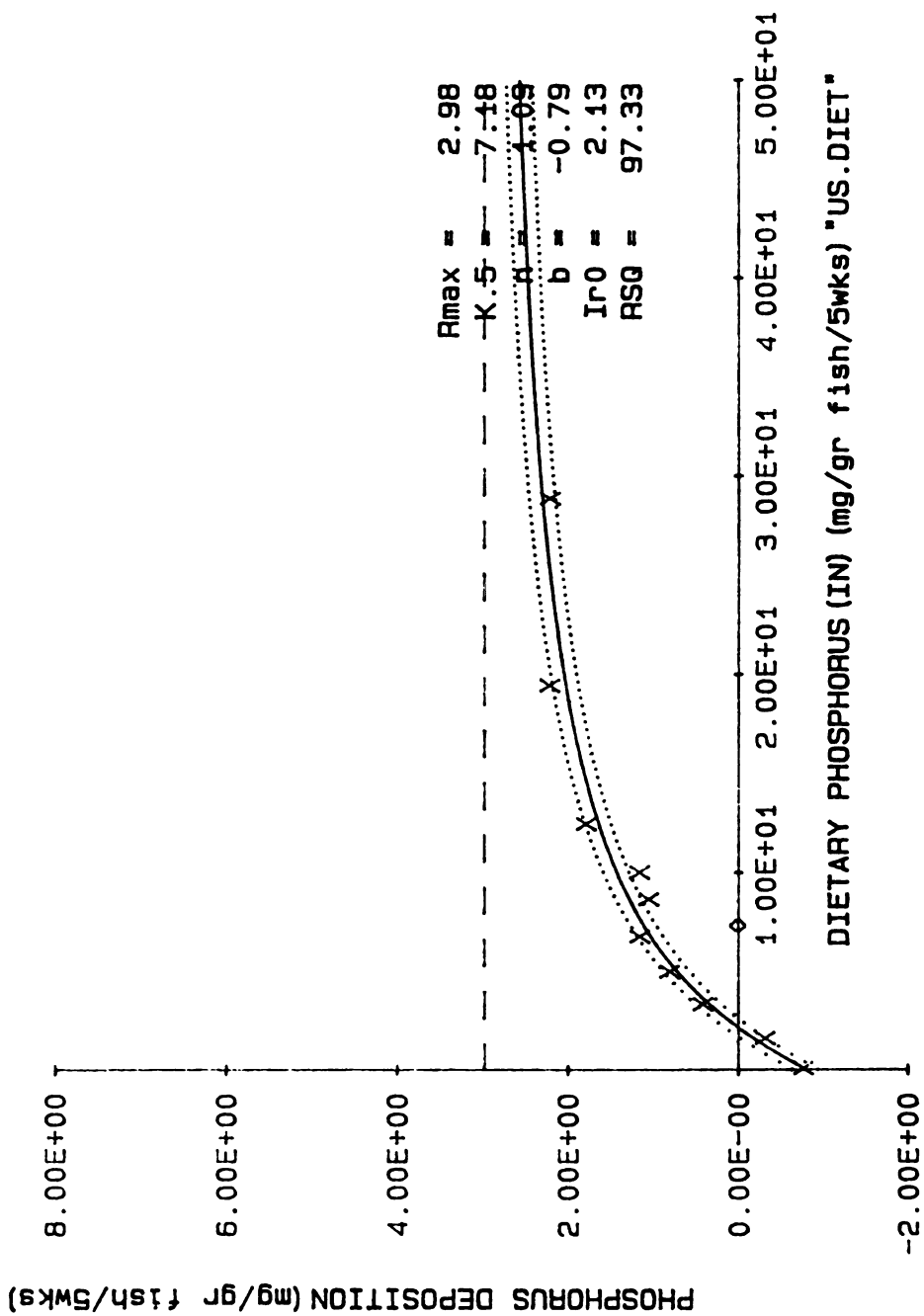


Figure 41. Theoretical nutrient response curve of phosphorus intake vs. phosphorus deposition of *O. niloticus* fed the U.S. diet. (The dotted line is the 95% confidence limit and the (X)s are the observed group mean, $n=3$).

Table 54. Parameters derived from dietary phosphorus levels (mg/g fish (initial weight/five weeks) and phosphorus deposition (mg/g fish/5-week period).

Source of Diet	$R_{\max}^1$	$K0.5^2$	b^3	n^4	$Ir=0^5$	$\% BW^6$	I_{enz}^7	$\% BW^8$	R_{enz}^8	R_{enz}^9	R_{enz}^{10}
HONDURAS	ab 1.95 ± 0.31	b 5.83 ± 1.46	a -1.45 ± 0.32	1.88 ± 0.71	5.83	0.71	5.38	0.77	0.14	0.25	0.249
THAILAND	a 4.89 ± 0.57	d 10.84 ± 1.95	a -1.52 ± 0.22	1.16 ± 0.21	4.2	0.54	2.56	0.35	0.72	0.40	0.30
PANAMA	bc 7.54 ± 0.83	c 8.67 ± 1.27	a 0.78 ± 0.61	2.25 ± 0.68	3.16		9.56		3.83	0.66	0.48
INDONESIA	b 7.57 ± 0.38	b 9.1 ± 0.72	a -1.2 ± 0.11	1.33 ± 0.15	2.28	0.49	4.01	0.79	1.0	0.54	0.48
U.S.A.	a 3.36 ± 1.03	a 8.54 ± 4.44	a -0.79 ± 0.35	1.05 ± 0.22	2.15	0.66	0.25	0.08	-0.69	0.40	0.24

1 $R_{\max}$: The maximum theoretical response.

2 $K0.5$: The intake level at half maximum response.

3 b : The response at zero intake level.

4 n : The kinetic order.

5 $Ir=0$: The intake at zero response (maintenance).

6 $\% BW$: Daily food intake as a percentage of body weight for the previous column.

7 I_{enz} : The intake at maximum efficiency.

8 R_{enz} : The response at maximum efficiency.

9 R_{enz} : Maximum efficiency.

10 R_{enz} : Overall efficiency.

the HD, TD, and AD. Fish fed the TD had a higher $R_{\max}$ value than those fed the HD and were not significantly different from those fed the AD.

The amount of dietary phosphorus fed that produces half $R_{\max}$ of phosphorus deposition in the fish is represented by $K0.5$. Fish fed the TD, PD, ID and AD were not significantly different from each other in terms of their $K0.5$ values. Fish fed the HD had lower $K0.5$ values than those fed TD, PD, and ID and were not significantly different from those fed the AD.

Fish fed zero dietary phosphorus had negative phosphorus deposition were not significantly different in the group of fish fed the HD, PD, ID, and AD. Fish fed no phosphorus of the TD group had significantly higher phosphorus deposition than those fed the PD, ID, and AD and were not significantly different from those fed the HD in terms of the negative phosphorus deposition (b). The kinetic order (n) showed a sigmoidal ($n>1$) relationship between dietary phosphorus intake and deposition in the fish.

The amount of dietary phosphorus fed at maintenance (no gain or loss) is represented by $Ir=0$. Fish fed the AD had the best $Ir=0$ value of all diets (lowest dietary phosphorus intake), followed by the group of fish fed the ID, PD, TD and HD, respectively. The maximum efficiency value for dietary phosphorus deposition in the fish for each diet was represented by $E_{\max}$. Fish fed the PD had the highest $E_{\max}$ value followed by the group fed the ID. Fish fed the AD and TD had some $E_{\max}$ value and were less than that of the group fed the ID.

Fish fed the HD had the least E_{mx} value of all. The efficiency value for dietary phosphorus deposition when fish were fed at $K_{0.5}$ value of intake were represented as the overall efficiency value. Fish fed the ID and PD had some and the highest overall efficiency value. Fish fed the TD had lower overall efficiency values than those fed the ID and PD. Fish fed the AD, and HD had similar overall efficiency values and were lower than fish fed the other test diets.

CHAPTER V

DISCUSSION

The primary goal of this study was to show that the saturation kinetic model (Morgan et al. 1975) can be used to describe O. niloticus weight gain and net nutrient deposition as a function of diet or nutrient intake. This was demonstrated graphically and numerically (Figures 2-41 and Tables 5-46) in the Results section. These results demonstrated that the physiological responses tested (dietary crude protein deposition, weight gain, net energy deposition, dietary CA, P, Mg, Zn deposition, and dietary crude fat deposition) could be predicted by the saturation kinetic model. The response could be calculated at any intake level using the model equation after estimating four parameters (b , $K_{0.5}$, N , $R_{\max}$):

$$r = \frac{b (K_{0.5})^n + R_{\max} I^n}{(K_{0.5})^n + I^n}$$

The second goal of this study was to use the model parameters to evaluate practical tilapia diets obtained from five different countries. The objective of the dietary evaluation was to determine which diet would maximize O. niloticus performance in terms of

physiological responses (weight gain and net nutrient deposition) and dietary (nutrient) efficiency. There are several possible methods of diet comparisons based on the four parameters of the saturation kinetic model:

1) A ratio of response for specific diet to the response for a standardized diet, at the same food intake level.

Since there is no standard O. niloticus diet and feed ingredients can vary in quality and composition especially, in different developing countries, this method was not chosen.

2) Comparison based on individual parameters such as $R_{\max}$ (the maximum theoretical response) and/or $K_{0.5}$ (the feed or nutrient intake at half maximal response).

3) Comparisons based on derivatives of the model such as the maximum efficiency ($E_{\max}$), the food (nutrient) intake at maintenance level on zero response ($I_r=0$; Mercer et al. 1978), and the dietary or nutrient efficiency at half maximal response $E_{\max.5}$.

Maximum efficiency ($E_{\max}$) gives the highest food conversion that a diet or nutrient could possibly have under the experimental conditions (Mercer et al. 1978). The efficiency at half maximal response gives the overall efficiency or conversion rate for specific diet or nutrient. The second and the third comparison methods were used in this study.

If one is interested in approaching maximum response under certain economical conditions (nutrient or food supply is not limiting

in countries such as the United States and Canada) the maximum theoretical response $R_{\max}$ may be the best comparative choice. The greater the $R_{\max}$ the better the diet or nutrient. On the other hand if one is interested in dietary (nutrient) efficiency or nutrients or food supply is limited, which is the case in most of the developing countries, the efficiency parameters should be used. The efficiency parameters include: 1) $K_{0.5}$, half maximum response; 2) $I_r=0$, dietary (nutrient) intake for maintenance; 3) $E_{\max}$; maximum efficiency; 4) The overall efficiency values ($E_{\max.5}$).

Growth

Wang et al. (1985) studied the dietary energy and protein requirements for O. niloticus size 3-5g. They reported that O. niloticus requires 25 percent crude protein and 67-71 mgCp/kcal DE. The AD, PD, and HD were very close to meeting these nutrient requirements (Table 5). The ID had higher levels of protein and protein-energy ratios (32.68 and 94 mgCp/kcal ME) than the requirements. The TD on the other hand, had lower levels of protein and protein to energy ratio (17.29% and 54 Cp/kcal ME) than the requirements. Papontsoglou and Alexis (1986) studied protein requirements of gray mullet by feeding isocaloric diets varying in protein levels and Cp/ME ratio. They found that above 24 percent protein and 53 mgCp/kcal Me in the diets feed conversion continued to improve with increasing protein and Cp/ME ratio up to 60 percent and 144.93. Jauncy (1979) demonstrated that lower dietary protein level,

and increased dietary energy (ME from carbohydrate and/or lipid) for mirror carp, increased the protein efficiency ratio which illustrated that protein was spared by energy sources. Garling and Wilson (1976) demonstrated that optimum Cp/ME ratio produced maximum growth of channel catfish over a range of dietary protein to energy. In my study, the ID with a higher Cp/ME ratio than the optimum ratio produced higher growth rate than the AD, PD, and HD which contain the optimum Cp/ME ratios for O. niloticus. This show that protein quality of these test diets were not high enough to meet the requirement at optimum levels.

The results of my study are in agreement with the previous studies. The ID was superior to all other experimental diets in terms of its growth potential. The maximum theoretical response ($R_{\max}$) which measures the genetic potential of fish towards a specific diet was significantly higher in the ID than all other diets. This is probably due to the fact that the ID contained a higher level of protein and protein/energy (Cp/ME) ratio which compensated for poor quality protein as will be demonstrated in further discussion. The TD was not significantly different from the PD and HD in terms of their $R_{\max}$ value. However, the TD had less dietary protein and Cp/ME ratio than the PD and HD. The TD was the only extruded-type pellet of the diets tested. Extrusion involves extensive wetting and heating when compared to the steam pellet production (Hilton et al. 1981) which could result in formation of bonds between lipids and other compounds in the feed that cannot be broken by solvent alone (Pomeraz and Melcan

1978). Using traditional solvents, therefore, underestimate the dietary fat content of extruded pellets. Linsuman and Lowell (1984) found that acid hydrolysis pretreatment of extruded pellets doubled the yield of crude fat determination. This means that crude fat determination (Table 1) may have underestimated the dietary fat content of the TD by as much as 50 percent. Extensive heating and wetting improved digestion and absorption. Moist heat also results in the rupture of the starch granule and an irreversible change in the crystalline structure of the molecule (geletinization) that facilitate the enzymatic attack (Maynard et al. 1979). In conclusion the efficient energy source in the TD probably spared the dietary protein and improved the $R_{\max}$ value of the diet. The relatively lower $R_{\max}$ value of the AD was probably due to poor efficiency of utilization of the nutrient(s) and source(s) (e.g., lower absorption and/or dietary nutrient deficiency).

The $K_{0.5}$ value (the amount of food intake at half maximal response) of the ID was not significantly different from different ($P < 0.05$) the HD, PD, and TD. This indicated that $R_{\max}$ value of these diets did express their efficiency. The AD on the other hand had a higher $K_{0.5}$ value than that of ID, HD, and PD, but was not significantly different from the TD. This indicted that the AD was less efficient than the ID, PD and HP. Maximum efficiency values normally occurred at a lower food intake level than the overall efficiency value of the diets tested. The TD had a relatively high maximum efficiency value when compared to that of other tested diets.

However, this efficiency sharply declined to relatively lower overall efficiency values at higher food intake levels. This probably indicated that a nutrient reduced the dietary efficiency of the TD at higher food intake level, which was most likely related to lower protein content of the TD. All efficiency parameters ($I_r=0$, E_{mx} , and the overall efficiency) indicated the AD had poorer efficiency than all other test diets which support the previous conclusion that the AD was deficient in one or more essential nutrients or the feed was not very well absorbed.

Energy Deposition

In growing fish, part of stored energy is stored as protein and part is stored as fat (Cho, et al. 1980). The relative importance of protein and fat deposition depends on several factors. The two major factors are: 1) the balance of the available amino acids of dietary protein and 2) the amount by which the dietary energy intake exceeds the energy expended as heat (Cho et al. 1982). Proteins of higher biological value promote greater protein deposition than those of low value. Murai et al. (1984, 1985) have demonstrated with carp fingerlings that the higher the protein quality, the higher the energy deposition. When marginal excess of total energy intake (proteins, carbohydrates and fat) exceeds energy expended as heat, this results in deposition of a larger proportion of retained energy as protein. As the excess energy intake increases the total amount of protein deposited increases, but the proportion of the energy retained as fat

increases at a faster rate so that increasing the energy intake leads to an increase in the amount of energy retained as fat (Cho et al. 1982).

The maximum theoretical energy deposition showed no significant differences between the HD, PD, ID, and AD ($P < 0.5$). This indicated that $R_{\max}$ for energy deposition is similar between the test diets. This is in agreement with the nutritional concept that animals (fish) eat to meet their energy needs. Therefore, depending on the dietary energy efficiency, fish would eat different amounts of the test diets to reach $R_{\max}$ value of energy deposition. The total dietary energy at half maximum response ($K_{0.5}$) was higher in the AD than TD, PD, and ID but not different from the HD. This indicates that the AD is less efficient in terms of promoting the conversion of dietary energy to body energy. That is probably due to less energy absorption in the AD. Energy efficiency at maintenance level ($I_r=0$) showed that the PD was the most efficient followed by the ID, HD, TD, and the AD, respectively. The maximum efficiency values and the overall efficiency is in agreement with the dietary energy efficiency at maintenance level ($I_r=0$). The overall dietary energy efficiency for the five diets ranged between 11-26 percent which is in agreement with what was found in other juvenile fish (Pandian 1967a,b; Yoshida 1970; Chesney and Estenez 1976).

Dietary Protein Response

The amount of protein deposition per unit of protein fed has been

recommended by several researchers (Zeitoun et al. 1973; Rumsey and Ketola 1975) as a simple, useful, and practical expression of protein efficiency. The saturation kinetic model that was used in this study, however, gives much more information about dietary protein than a single value for protein efficiency. The model provides maximum protein deposition per gram of fish, the dietary protein intake at half maximum response, the dietary protein level that is necessary for maintenance (zero response), maximum efficiency, the overall efficiency, and gives the researcher opportunity to predict the amount of protein deposition at any dietary intake level during periods of time.

Dietary protein quality and protein to energy ratio are the two major factors that affect dietary protein deposition (Cho et al. 1982; Murai et al. 1984, 1985). The maximum theoretical responses of protein deposition of all tested diets were found to be highly correlated with dietary protein level and Cp/ME ratio ($r = 0.99$ and $r = 0.96$, respectively).

Murai et al. (1984) reported similar results in carp. They found a highly significant correlation coefficient between protein deposition and both dietary protein level and protein to energy ratio ($r = 0.91$ and $r = 0.97$, respectively).

The ID had the highest dietary protein level and Cp/ME ratio. Therefore the ID had the highest $R_{\max}$ values in terms of protein deposition. The TD had the lowest protein level and Cp/ME value, and had the lowest $R_{\max}$ value of all test diets. The AD, PD, and HD had

similar dietary protein levels and Cp/ME ratios and had insignificant differences between the three diets in terms of their $R_{\max}$ of protein deposition value ($P < 0.5$). The dietary protein that deposits half $R_{\max}$ value of protein in fish bodies ($K0.5$) was relatively high in the ID than that of the HD, TD, PD and was similar to that of the AD ($P < 0.5$). This indicates that the ID and the AD had less efficient protein than the HD, PD and TD. The $K0.5$ value of the TD was the lowest value of all feeds, which indicated the best protein efficiency of all diets. The higher efficiency value of the TD was probably due to protein sparing effect since the TD had the lowest dietary protein level an adequate level of available energy (carbohydrate and lipids). Juancy (1979) has demonstrated that at lower protein levels and higher metabolizable energy (CHO and/or lipids) protein efficiency was increased. This result is in agreement of the efficiency result of the TD. Other efficiency parameters ($I_r=0$, $E_{\max}$, and the overall efficiency value) showed some efficiency differences that was found in the $K0.5$ values. The overall dietary protein efficiency ranged between 25-57 percent.

Dietary Crude Fat Deposition

Total dietary fat intake was highly correlated to the maximum body fat deposition ($r = 0.91$) ($P < 0.5$) at the $R_{\max}$ value. Murai et al. (1984) observed a lower correlation ($r = 0.67$) than what was found in any feeding experiment in any study. Murai and coworkers

restricted feed intake and could not show the maximum dietary fat deposition. The AD had the highest dietary crude fat content and the highest $R_{\max}$ value in terms of dietary fat deposition of all test diets ($P < 0.5$). The TD on the other hand had higher crude fat content than the PD but lower $R_{\max}$ value in terms of fat deposition than the PD. This indicated that dietary fat content of the TD was utilized to spare protein. There was a high correlation coefficient ($r = 0.97$) between calculated metabolizable energy values and dietary fat deposition in the ID, HD, and PD. However, the correlation dropped ($r = 0.7$) if the TD was added and further dropped ($r = 0.5$) if the AD was added. The low correlation coefficient of the TD suggested that protein was spared by dietary energy sources (crude fat and carbohydrate). The low correlation coefficient of the AD was due to low dietary energy efficiency. The efficiency parameters ($K_{0.5}$, $I_r=0$, $E_{\max}$) and the overall efficiency of converting the dietary fat to body fat in O. niloticus showed that the PD was the most efficient diet. This was followed by the ID. The TD and HD had half the efficiency of the PD and ID, respectively. The AD was the most efficient.

Magnesium Deposition

There was low correlation ($r = 0.52$, $P < 0.5$) between the dietary magnesium content and the $R_{\max}$ value of maximum magnesium deposition. This indicated that magnesium absorption efficiency varied between feeds. Two factors can affect the total body magnesium

content, the dietary magnesium intake and the availability of magnesium (Delbert et al. 1982). The magnesium efficiency parameters ($K_{0.5}$, $I_r=0$, E_{max} , and the overall efficiency values) showed differences between diets. These difference were probably due to the source of magnesium and/or some other dietary factor.

From the dietary magnesium deposition results, it was concluded that the higher levels of magnesium in the ID and PD were unnecessary and could be decreased.

Dietary Calcium Deposition

All five tested diets contained higher levels of dietary calcium than levels recommended for tilapia (Table 30). The ID had the highest calcium content of all diets, the highest R_{max} value of calcium deposition, and the lowest efficiency value of all tested feeds. The PD, HD, TD and AD had similar dietary calcium content and R_{max} value for calcium deposition, however, they varied in their dietary calcium efficiency. These results indicated that dietary calcium efficiency was affected by the calcium intake level (dietary calcium concentration) and calcium availability. Calcium availability is affected by the vitamin D level and/or the chemical form of calcium contained in those diets.

Zinc Deposition

There are several factors that affect dietary zinc requirement levels (maintain an optimum level of zinc in the fish body) such as

calcium level (Forbes 1960), phytic acid (Oberteas 1962), and protein sources (Zigler et al. 1961 and Smith et al. 1962). The maximum theoretical response of zinc deposition was highly correlated with the dietary zinc levels of the Indonesian, Honduran, Thailand and American diets ($r = 0.99$). If you add the values of the Panamanian diet the correlation coefficient will drop to $r = 0.83$. These results show that a factor other than zinc intake affected dietary zinc deposition through reducing zinc absorption. This could have been caused by any of the above factors. Additionally, the Panamanian diet was generally high in mineral content, which could have affected zinc absorption. The Indonesian and Panamanian diets produced the lowest zinc deposition efficiency. This could probably be due to high dietary calcium in the Indonesian diet and also any of the above factors that affect zinc availability.

Dietary Phosphorus Deposition

The maximum theoretical dietary phosphorus deposition was affected by the intake level, which was generally higher than the recommended level of phosphorus (Table 30) with exception of the TD, and the dietary phosphorus efficiency. The PD had the highest dietary phosphorus of all diets and the highest $R_{\max}$ value of phosphorus deposition. The ID had higher dietary phosphorus content of the HD, TD, and AD. The ID had higher $R_{\max}$ value than the HD, TD and AD. Dietary phosphorus efficiency parameters ($K_{0.5}$, $I_r=0$, $E_{\max}$, and the overall efficiency value) (Table 44) showed differences between

dietary phosphorus efficiency. That was probably due to the same type of factors that affected calcium absorption (NRC 1983).

CHAPTER VI

SUMMARY AND DISCUSSION

It was demonstrated that physiological responses (weight gain, crude fat deposition, crude protein deposition, gross energy deposition, calcium, phosphorus, magnesium and zinc deposition) to graded levels of dietary (nutrient) intake of each of five practical tilapia feeds and can be analyzed by the four parameters of the saturation kinetic model. By definition, all responses were sigmoidal ($n > 1$); however, some responses were close to being hyperbolic when graphed.

In terms of the maximum theoretical response value ($R_{\max}$), the ID had the highest value for weight gain of all tested diets. Other diets tested had similar weight gain response.

In terms of the dietary efficiency the ID was the best diet of all tested diets based on weight gain. The PD was the second most efficient diet followed by TD, HD, and AD, respectively.

Dietary mineral concentrations were generally higher than the recommended levels (Table 30) which indicated that those levels should be adjusted downward according to their efficiency values.

The AD had the lowest dietary efficiency values when compared to all test diets. However, the AD is economically feasible as a

commercial tilapia feed. Efforts must be made to improve the dietary efficiency since too much nutrients are wasted.

In conclusion, the saturation kinetic model is an effective tool in dietary evaluations for O. niloticus. It could be expanded to include economic analysis if feed cost were available (i.e. cost x $R_{\max}$ = cost of maximum production or cost x efficiency parameter = cost of production of $E_{\max}$ or at any calculated efficiency level that is economically feasible).

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APPENDIX I

APPENDICES

APPENDIX I (El-Sayed, 1987)

During the early 1980's, the genus tilapia was subdivided into two genera based on parental care behavior. The genus Tilapia was restricted to tilapia species which lack parental mouthbrooding of eggs and young, while the subgenus name Sarotherodon was elevated to genus status and given to the species of tilapia with parental mouthbrooding of eggs and young. Later, the genus Sarotherodon was subdivided into two genera; Sarotherodon and Oreochromis based on whether parental females (O.), males (S.) or both parental sexes (S.) perform the mouthbrooding behavior. Although there is considerable argument over whether these fishes are truly separate species, for the purpose of this Ph.D. thesis, the genera names used will follow the current convention of:

Tilapia = species of tilapia which lack mouthbrooding.

Sarotherodon = species of tilapia with male or biparental (both male and female) mouthbrooding behavior.

Oreochromis = species of tilapia with female mouthbrooding behavior.

regardless of the genus name used by authors of the original cited papers. The only exception to the use of current tilapia genera names will be in the literature cited section. The term tilapia will be used to describe all three of these closely related genera.

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