RHODIMET® NUTRITION GUIDE

Amino Acid Recommendations for feed formulation, 2013

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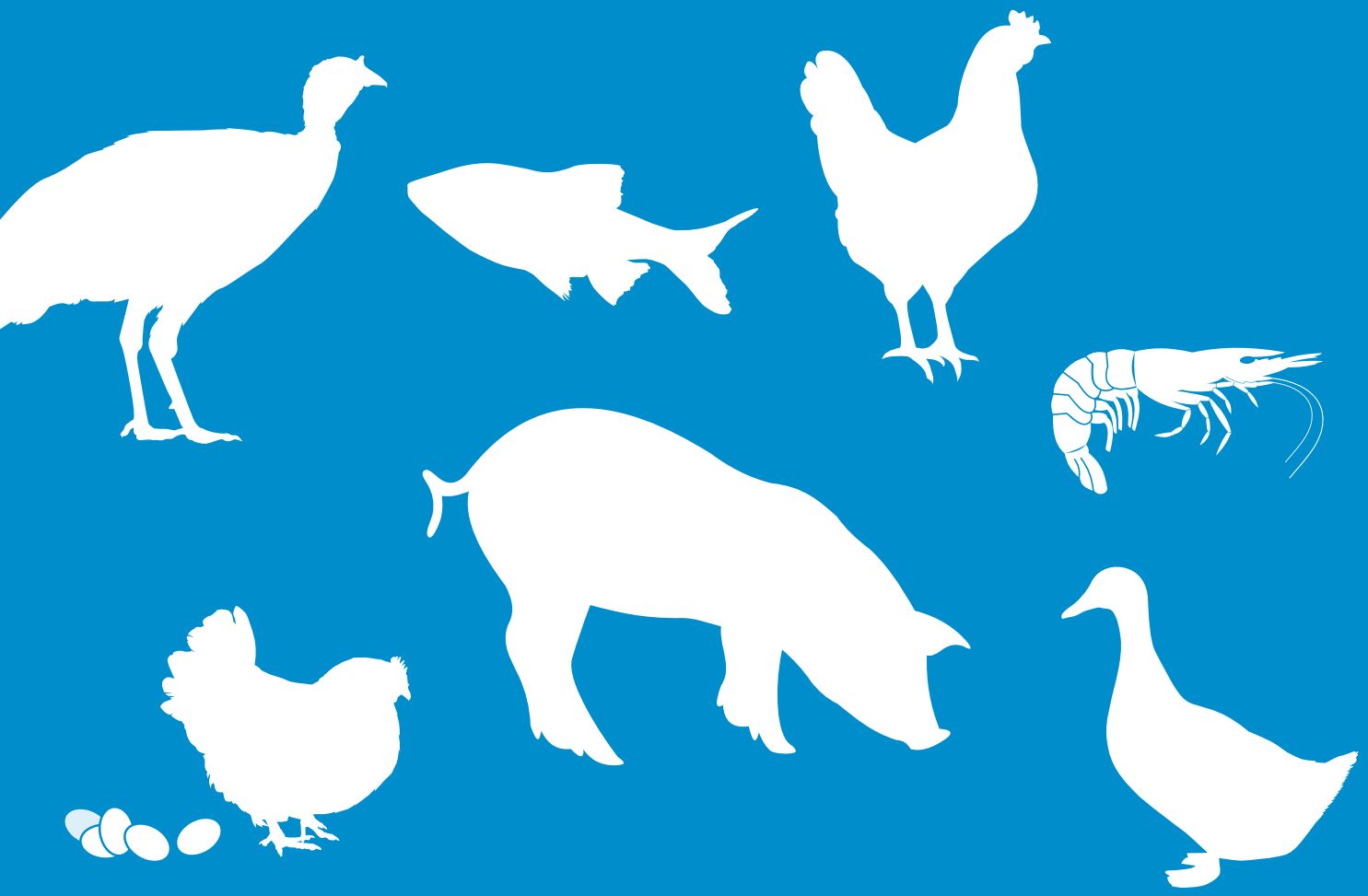

We are very pleased to provide you with this updated version of the amino acid recommendations for poultry, swine, fish and shrimp, which has been compiled through the analysis of more than 223 peer-reviewed papers, including data sets issued from several Rhodimet® Research Grant programs.

This document is an extract of the electronic version of the Rhodimet® Nutrition Guide, an interactive tool that allows users to calculate the amino acid requirements of various animal strains in different rearing conditions, with a complete list of scientific references.

This valuable tool should facilitate your daily task of formulating the most cost effective diet from an amino acid point of view, while ensuring the optimization of weight gain and breast meat yield or egg mass.

We would like to thank the authors Dr. Magalie Nonis and Pierre Dalibard for their active participation in this work as well as all contributors with particular thanks to the Advancia Community.

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SUMMARY

ABBREVIATIONS

AA: Amino acid
ADG: Average Daily Gain
BM: Breast Meat
DAA: Digestible Amino Acid
DE: Digestible Energy
DFI: Daily Feed Intake
DP: Digestible Protein
EAA: Essential Amino Acids
EM: Egg Mass
FCR: Feed Conversion Ratio
ME: Metabolizable Energy
NE: Net Energy
NEAA: Non-Essential Amino Acids
SID: Standardized Ileal Digestibility
d: day
dig: digestible
g: grams
g/d: grams per day
g/g: grams per gram
kg: kilograms
mg/d: milligrams per day
wk: week
x: independent variable
y: dependant variable

FIGURES AND TABLES

INTRODUCTION

Protein represents the sum of all amino acids and is a qualitative generic term in animal nutrition that can significantly influence the cost of feed. While animals do not have a protein requirement per se, they do have different amino acid requirements for different stages of growth and production.

An amino acid requirement can be defined as the minimum amount of one amino acid that maximizes the use of other essential amino acids[1] for de novo protein synthesis. The commercial availability of synthetic essential amino acids has resulted in a better understanding of the animal's requirements for individual essential amino acids and enabled nutritionists to more precisely formulate rations, manage expensive protein sources, reduce the excess of other essential and non-essential amino acids, and reduce dietary crude protein levels. Altogether, this not only increases the efficiency of livestock production but also generates lower feed costs and nitrogen excretion into the environment.

Historically, minimal and optimal amino acid requirements for weight gain, feed conversion, breast meat and egg mass have been estimated in experimental trials using quadratic, broken line and exponential mathematical models. Amino acid recommendations from these studies are often expressed on a digestible and ideal protein basis, where the digestible level of an essential amino acid is expressed as a proportion of digestible lysine in the diet, the reference amino acid (digestible essential AA/digestible lysine). An ideal protein profile is supposed to contain adequate quantities of each essential amino acid to satisfy the requirements for maintenance and production.

In 2002, Geraert *et al.* proposed an innovative factorial model approach for determining amino acid requirements (g/d) according to weight gain (in g/d) of growing animals or egg mass (in g/d) of layers. Using data obtained from an extensive survey of published literature on the amino acid requirements of poultry, swine and aquaculture from the last 22 years (more than 200 articles for poultry and swine), this approach has been adopted for this latest update of the Rhodimet® Nutrition Guide (Rhodimet® NG). Such updates are important as the genetic potential of animals continues to improve and as livestock production practices and objectives change over time.

[1] Methionine in the form of DL-Methionine and DL-2-hydroxy-4-(methylthio) butanic acid (DL-HMTBA), L-Arginine, L-Histidine, L-Lysine, L-Threonine, L-Valine, L-Tryptophan, Histidine, Isoleucine, Leucine and Phenylalanine.

METHODOLOGY

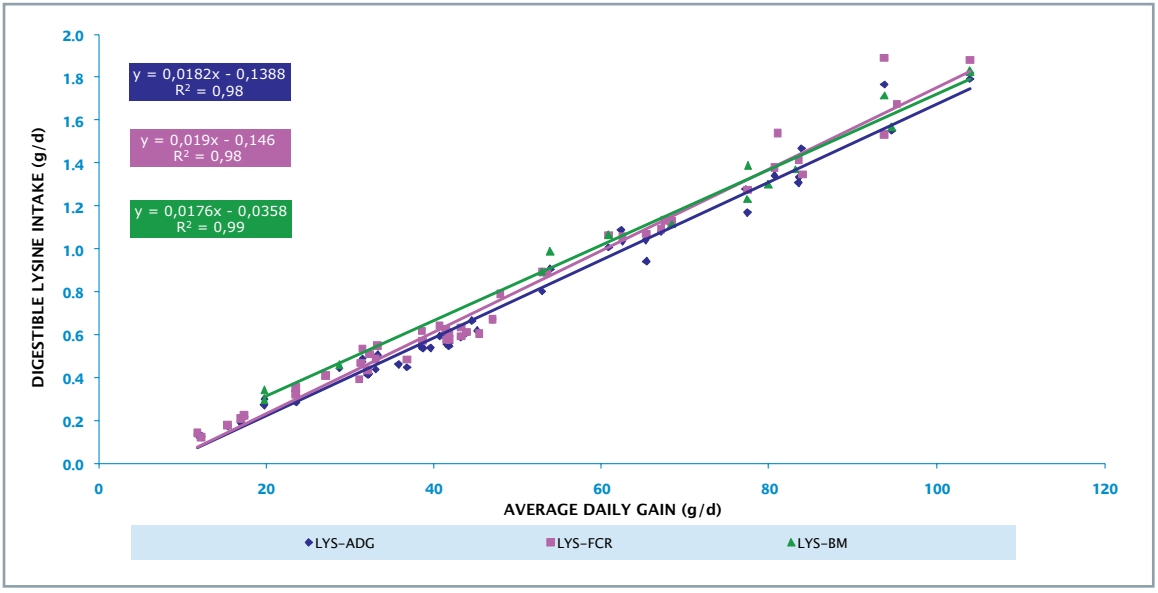
The Rhodimet® NG has been updated for all the major poultry species (including broilers, pullets, laying hens, turkeys and ducks), swine (including piglets, growing-finishing pigs, replacement gilts, gestating and lactating sows, intact males and sexually mature boars), and aquaculture species (fish and shrimp).

The amino acid recommendations in the Rhodimet® NG are expressed on a digestible, and not on a total, amino acid basis (with the exception of ducks, fish and shrimp). Only experiments from 1990 that satisfied the following criteria were retained for analysis: designed to estimate an amino acid requirement and had at least four amino acid levels, reported at least daily weight gain, egg mass, feed intake and/or feed conversion, modeled the response curve to a particular amino acid using a linear model (quadratic function) or a non-linear model (linear plateau, curvilinear plateau or asymptotic), and had a detailed description of the diet composition. If the authors did not provide any detailed information on the composition of experimental diets, the digestible AA contents of the diets were calculated using the total AA and true AA digestibility coefficients of feedstuffs from the Rhodimet® NG (version 2.08).

While AA requirements for certain species in the Rhodimet® NG were obtained from published recommendations for fish and shrimp (adapted from NRC, 2011), replacement gilts, gestating and lactating sows, intact males and sexually mature boars (adapted from NRC, 2012), ducks (from Grimaud Frères Sélection, 2010a and 2010b), and pullets (from ISA, 2009 and Hy-line International, 2012), the digestible AA recommendations for broilers, laying hens, turkeys, piglets and growing-finishing pigs were derived from the methodology as applied and described by Geraert *et al.* (2002, 2005). These requirements are expressed on an AA intake in grams per animal and per day, in relation to the average daily gain for growing animals or daily egg mass for layers. This assumes that, whatever the genotype, a constant quantity of amino acids per day is necessary to obtain a given level of performance, and that the levels of amino acids needed per day will increase linearly with daily gain or egg mass. In other words, the performance of an animal during a growth or production period is predicated on the level of amino acids required per day, at a given level of feed intake per day.

As an example, the digestible lysine requirement of broilers (g/d) in relation to average daily gain (g/d) for three optimized criteria: daily gain, feed conversion and breast meat, are shown in Figure 1. The equations resulting from these analyses demonstrate good correlations between digestible lysine intake and growth rate.

Figure 1: Minimum digestible lysine intake (g/d) for optimal weight gain (g/d), feed conversion ratio (g/g) or breast meat (g) of broilers (literature review covering various periods from 1 to 42 days: ADG, 53 trials; FCR, 49 trials and BM, 16 trials).



This methodology was also used, when applicable, for methionine, methionine + cystine, threonine, tryptophan, arginine, isoleucine and valine for broiler, laying hen, turkey and pig requirements. Equations are presented in each section.

The recommendations for other amino acids such as histidine, leucine, phenylalanine + tyrosine, and those for which the methodology was not applicable due to a limited number of experiments, were calculated according to an ideal protein profile with lysine as the reference amino acid.

In this version of the Rhodimet® NG, the amino acid recommendations for replacement gilts, intact males and sexually mature boars are not presented but are available in the electronic version of the Rhodimet® NG. The levels of amino acids suggested below should be seen as a guide under optimal conditions. There are obviously factors such as dietary energy level, ambient temperature, lean-gain type and/or house density that can influence optimal dietary amino acid requirements. The impact of these factors, when applicable, can be simulated with the electronic Rhodimet® NG.

POULTRY

RECOMMENDATIONS FOR BROILERS

DIGESTIBLE AMINO ACID REQUIREMENTS IN G/D:

Amino acid recommendations are given on the basis of standardized ileal digestible amino acids (SID). Modelling equations are available for lysine, methionine, methionine + cystine, threonine, tryptophan, arginine, isoleucine and valine.

Table 1: Modelling equations for predicting digestible amino acid requirements (y, g/d) of broilers according to average daily gain, feed conversion ratio and breast meat (x, g/d).

Criterion	ADG		FCR		Breast Meat	
	Equation	R^2	Equation	R^2	Equation	R^2
Lysine	y=0.0182 x-0.1388	0.98	y=0.0190 x-0.1460	0.98	y=0.0176 x-0.0358	0.98
Methionine	y=0.0074 x-0.0253	0.95	y=0.0084 x-0.0505	0.93	NA	NA
Met + Cystine	y=0.0133 x-0.0440	0.95	y=0.0140 x-0.0668	0.97	NA	NA
Threonine	y=0.0117 x-0.0811	0.91	y=0.0116 x-0.0792	0.97	NA	NA
Tryptophan	y=0.0033 x-0.0134	0.92	y=0.0032 x-0.0100	0.90	NA	NA
Arginine	y=0.0181 x-0.0466	0.97	y=0.0194 x-0.0831	0.97	NA	NA
Isoleucine	y=0.0118 x-0.0461	0.95	y=0.0126 x-0.0749	0.95	NA	NA
Valine	y=0.0144 x-0.0850	0.97	y=0.0139 x-0.0943	0.98	NA	NA

Figure 2: Minimum digestible amino acid intake (g/d) for optimal weight gain of broilers (g/d): lysine, 53 trials; methionine, 12 trials; methionine + cystine, 14 trials; threonine, 31 trials; tryptophan, 28 trials; arginine, 8 trials; isoleucine, 12 trials and valine, 10 trials; covering various periods from 1 to 42 days.

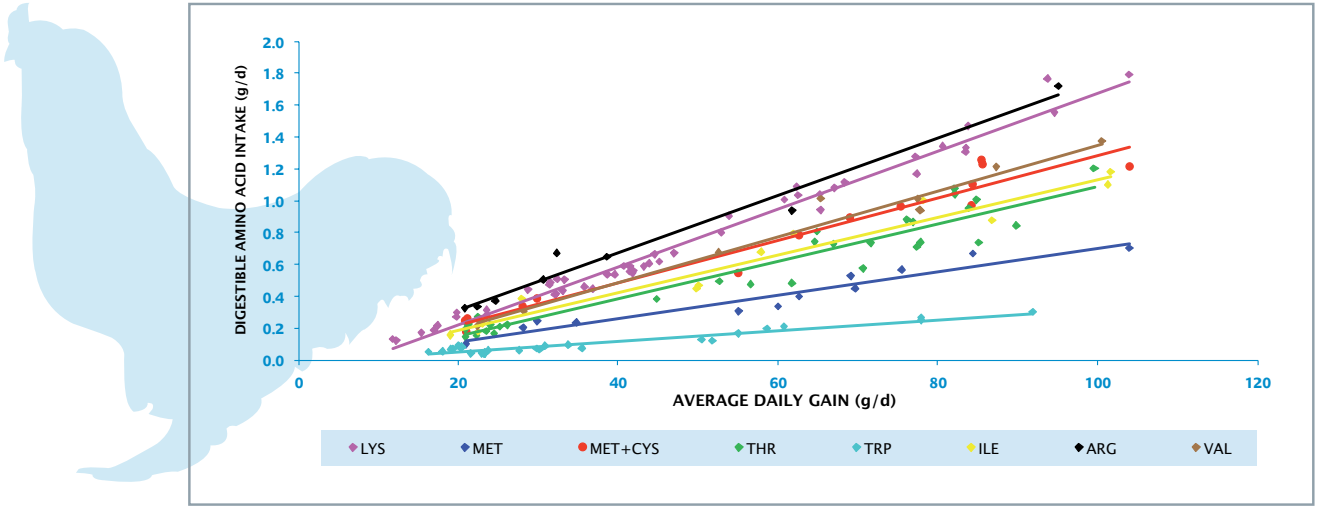
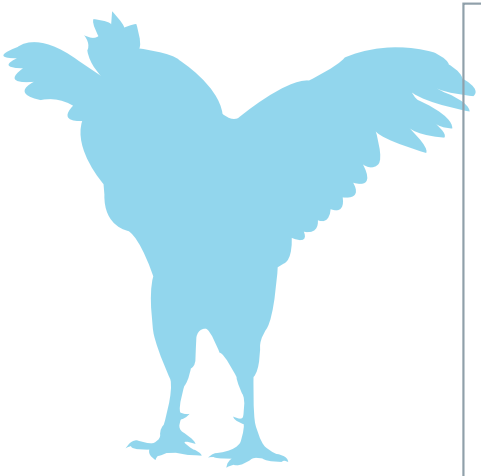
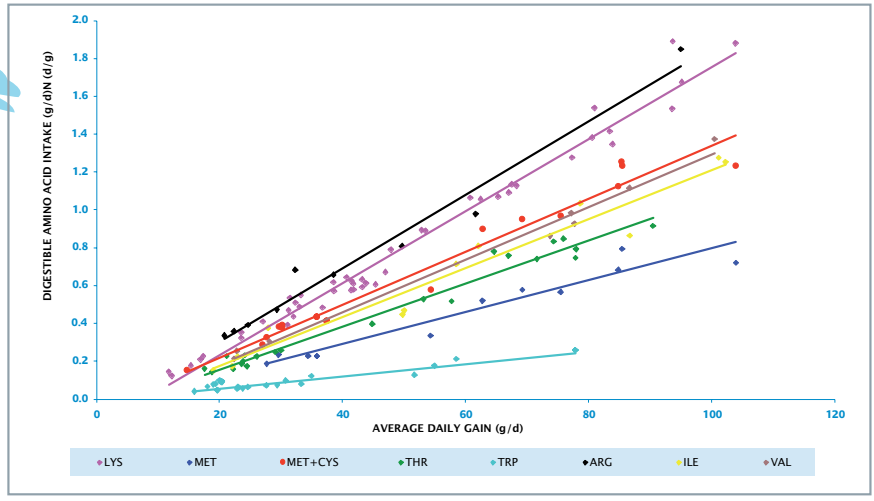


Figure 3: Minimum digestible amino acid intake (g/d) for optimal feed conversion ratio of broilers (g/d): lysine, 49 trials; methionine, 12 trials; methionine + cystine, 18 trials; threonine, 23 trials; tryptophan, 24 trials; arginine, 9 trials; isoleucine, 9 trials and valine, 8 trials; covering various periods from 1 to 42 days.





IDEAL PROTEIN PROFILES:

For histidine, leucine, phenylalanine + tyrosine, the amino acid / lysine ratios were obtained from an average of profiles taken from published literature for broilers (Table 2).

Table 2: Ideal digestible amino acid profiles used to complement the broiler model (%).

	Coon (2004)		Rostagno (2011)		Corrent and Bartelt (2011)
	ADG	FCR	1-21d	22-56d	
Lysine	100	100	100	100	100
Histidine	34	37	37	37	40
Leucine	113	116	107	108	105
Phe + Tyrosine	119	123	115	115	105

In addition, recent work on met+cys levels and optimal breast-meat development has been taken into account. Pessoa *et al.* (2012) evaluated the digestible met+cys requirements in early life of broiler chicks for growth performance and breast-fillet development. They showed that the requirements were largely underestimated regarding the linear breast-fillet response. Breast fillet development responded linearly up to 80% for met+cys/lys ratio in the pre-starter (1-10 d) and starter (11-21d) phases. Rostagno (2012) showed that 42 day-old broiler males fed diets with met+cys/lys ratios of 77% in the pre-starter, 78% in the starter and 78% in the growing-finishing phases had higher fillet weight than those fed the diets with the respective ratios of 72%, 72% and 73%. The high met+cys/lys ratios have been used to calculate the requirements for optimal breast-meat production in Table 3.

As an example, the digestible amino acid recommendations for male and female Ross 308 broilers were estimated using the broiler equation models and the growth performance published by the Aviagen breeding company.

Table 3: Example of calculated digestible amino acid recommendations for broilers (% diet).

		Male				Female			
		Age				Age			
		1-10d[1]	11-22d	23-35d	36-42d	1-10d[1]	11-22d	23-35d	36-42d
ME[2]	kcal/kg	3 025	3 150	3 200	3 200	3 025	3 150	3 200	3 200
	MJ/kg	12.65	13.20	13.40	13.40	12.65	13.20	13.40	13.40
Performance of reference[3]	ADG	25	61	94	104	25	56	79	83
	DFI	30	87	168	221	30	80	145	185
Lysine	ADG	1.08	1.12	0.94	0.79	1.04	1.09	0.89	0.74
	FCR	1.12	1.16	0.98	0.83	1.08	1.14	0.93	0.77
	BM	1.38	1.19	0.97	0.81	1.34	1.18	0.93	0.77
Methionine	ADG	0.54	0.49	0.40	0.34	0.53	0.48	0.38	0.32
	FCR	0.54	0.53	0.44	0.37	0.52	0.52	0.42	0.35
Met + Cystine	ADG	0.98	0.88	0.72	0.60	0.95	0.87	0.69	0.57
	FCR	0.96	0.90	0.75	0.63	0.93	0.89	0.71	0.59
	BM	1.06	0.93	0.75	0.63	1.03	0.92	0.73	0.60
Threonine	ADG	0.72	0.73	0.61	0.51	0.69	0.71	0.58	0.48
	FCR	0.72	0.72	0.60	0.51	0.69	0.71	0.58	0.48
Tryptophan	ADG	0.24	0.22	0.18	0.15	0.23	0.21	0.17	0.14
	FCR	0.24	0.21	0.17	0.15	0.23	0.21	0.17	0.14
Arginine	ADG	1.38	1.22	0.99	0.83	1.34	1.20	0.95	0.78
	FCR	1.37	1.26	1.04	0.87	1.33	1.25	1.00	0.82
Isoleucine	ADG	0.85	0.77	0.64	0.53	0.82	0.76	0.61	0.50
	FCR	0.82	0.80	0.66	0.56	0.79	0.78	0.63	0.52
Valine	ADG	0.94	0.91	0.76	0.64	0.90	0.90	0.72	0.60
	FCR	0.86	0.87	0.72	0.61	0.83	0.85	0.69	0.57
Histidine	ADG	0.40	0.41	0.35	0.29	0.38	0.40	0.33	0.27
	FCR	0.42	0.43	0.36	0.31	0.40	0.42	0.34	0.28
Leucine	ADG	1.18	1.22	1.02	0.86	1.13	1.19	0.97	0.80
	FCR	1.22	1.27	1.07	0.90	1.18	1.24	1.02	0.84
Phe + Tyrosine	ADG	1.24	1.28	1.08	0.91	1.19	1.26	1.03	0.85
	FCR	1.29	1.34	1.13	0.95	1.24	1.31	1.07	0.89

[1] cumulated feed intake of 295 g/broiler / [2] Ross 308 (2012) / [3] Ross (2009); ADG and DFI were calculated as being the average for the period

Table 4: Ideal digestible amino acid profiles for broilers (%).

	Age		
	1-10d	11-22d	23-42d
Lysine[1]	100	100	100
Methionine[1]	50	45	44
Met + Cystine[1]	85	78	77
Threonine[1]	65	64	63
Tryptophan[1]	22	19	18
Arginine[1]	126	109	106
Isoleucine[1]	76	69	68
Valine[1]	82	78	77
Histidine[2]	37	37	37
Leucine[2]	109	109	109
Phe + Tyrosine[2]	115	115	115

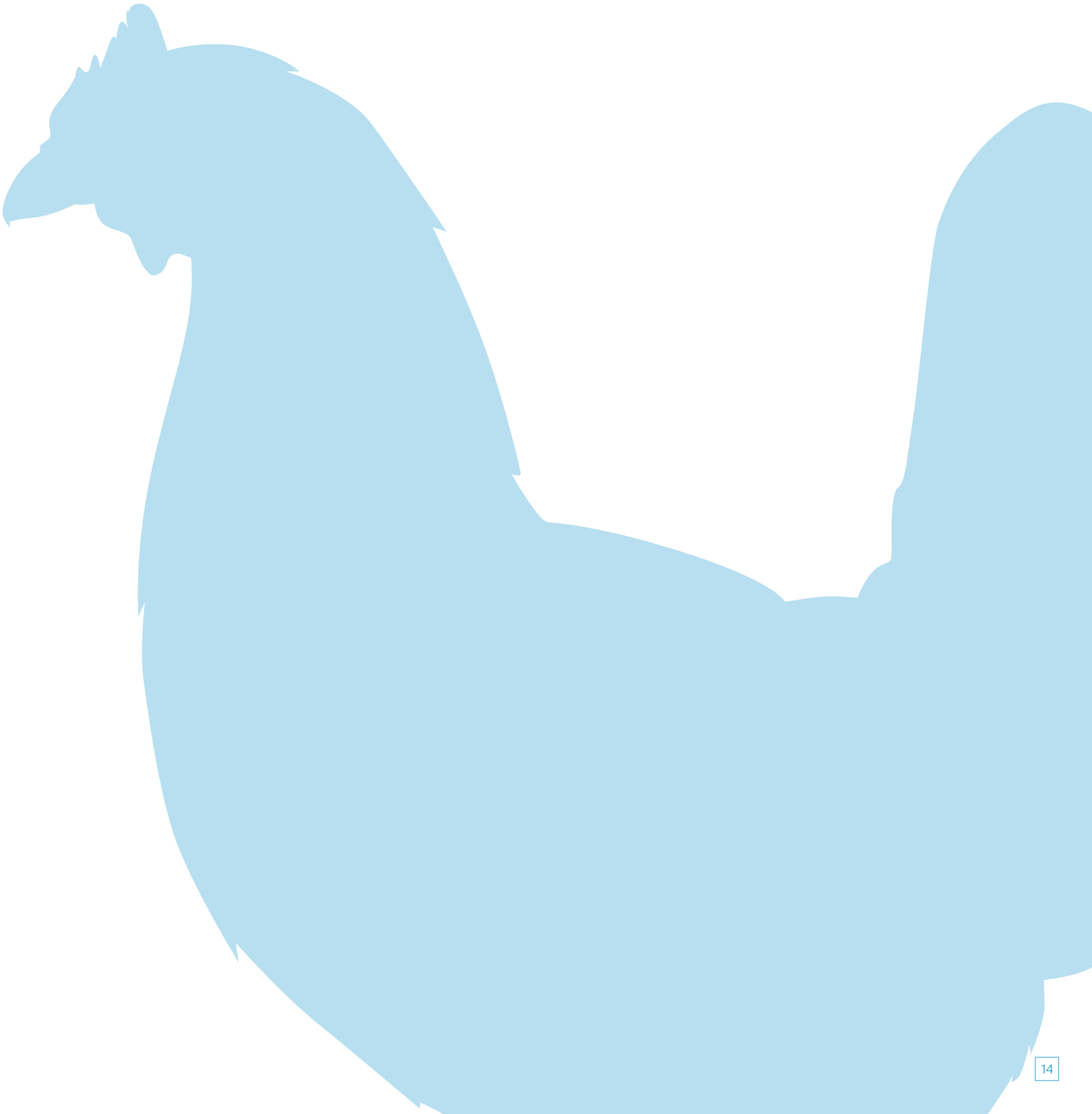
[1] DAA/lysine ratio based on regressions on optimal performance.
[2] DAA/lysine ratio based on published ideal protein profiles.

AMINO ACID RECOMMENDATIONS FOR HEAVY BROILERS:

Amino acid requirements for late-finishing broilers - beyond 42 days of age – need further evaluation. Broilers at a heavy weight have large differences in requirements between growth and maintenance. The existing data for amino acid requirements in literature could not be fitted into the linear models because, as birds get older, daily feed intake increases while daily gain decreases. For information, the digestible lysine requirement was estimated as 0.87% (male) and 0.81% (female) for growth performance and 0.90% (Dozier *et al*., 2008) and 0.93% (Corzo *et al*., 2006) for breast-meat yield in the male broiler. The digestible met+cys to lysine ratio was estimated to be 71% for breast yield and breast-fillet yield (Atencio *et al*., 2004); 74% and 77% (Dozier *et al*., 2012) for total meat weight and yield, respectively. Total dietary threonine for optimal growth rate, feed to gain ratio and fillet weight was estimated to be 0.74% for male and 0.63% for female (Dozier and Moran, 2001) and, in another study, the optimal levels for body weight gain and feed conversion ranged from 0.60% to 0.67% (Kidd *et al*., 2003).

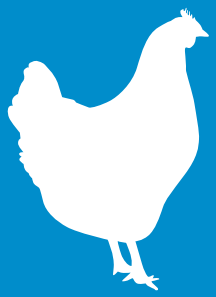
NON-ESSENTIAL AMINO ACID RECOMMENDATIONS:

The NEAA, which include alanine, cystine, glycine + serine, proline, tyrosine, glutamic acid and aspartic acid, can be synthesized from other amino acids (including essential amino acids, EAA) or nitrogen by the chicken, and so are not necessarily required in the diet. The increased availability of commercially available EAAs at viable costs enables a reduction in dietary crude-protein levels, but the extent to which this can be done without negatively affecting broiler performance is still unknown. From a formulation and nutrition standpoint, low crude protein diets fortified with an array of EAAs contain a lower NEAA/EAA ratio than diets that are strictly composed of amino acids from intact protein. According to Aftab *et al.* (2006) the ratio of NEAA/EAA should be maintained around 50:50. When the balance of NEAA/EAA is further evaluated, it appears that broiler performance is improved when low crude-protein diets are supplemented with glycine, but not with a mixture of other NEAA (Parr and Summers, 1991; Jiang *et al*., 2005; Dean *et al*., 2006; Yuan *et al*., 2012). The fact is that when broilers are fed reduced protein diets, they respond positively to supplemental glycine above the NRC (1994) suggested levels (1.25% and 1.14% for starter and grower periods). This suggests that glycine deficiency in reduced protein diets is a potential reason for poor performance of broilers (Aftab *et al*., 2006).



POULTRY

RECOMMENDATIONS FOR PULLETS



Because of the limited number of scientific publications, it has not been possible to model the amino acid requirements of pullets. The following requirements have been adapted from the recommendations given by layer breeders.

Table 5: Digestible amino acid recommendations for pullets - semi-heavy strains (% diet).

		Starter		Grower		Developer	
		Age		Age		Age	
		0-4wk	0-5wk	4-10wk	5-10wk	10-16wk	
		1-28d	1-35d	28-70d	35-70d	70-112d	
Temperature		18-24°C	>24°C	18-24°C	>24°C	18-24°C	>24°C
ME	kcal/kg	2 950-2 975	2 950-2 975	2 850-2 875	2 850-2 875	2 750	2 750
	MJ/kg	12.3-12.4	12.3-12.4	11.9-12.0	11.9-12.0	11.5	11.5
Crude Protein		20.5	20.5	19	20	16	16.8
Lysine		1.00	1.00	0.85	0.89	0.64	0.67
Methionine		0.48	0.48	0.41	0.43	0.30	0.32
Met + Cystine		0.78	0.78	0.66	0.69	0.53	0.56
Threonine		0.67	0.67	0.57	0.61	0.43	0.45
Tryptophan		0.19	0.20	0.17	0.18	0.15	0.15

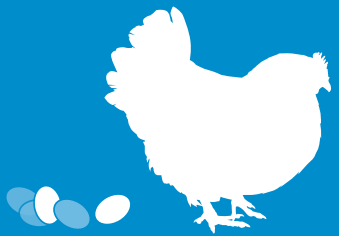
(from ISA, 2009)

Table 6: Digestible amino acid recommendations for pullets - light strains (% diet).

		Starter 1	Starter 2	Grower	Developer	Pre-lay
		Age		Age	Age	Age
		0-3wk	4-6wk	7-12wk	13-15wk	16-17wk
Feed to a body weight of		170g	410g	940g	1 160g	1 240g
ME	kcal/kg	2 977-3 087	2 977-3 087	2 977-3 131	2 911-2 955	2 911-2 955
	MJ/kg	12.46-12.92	12.46-12.92	12.46-13.11	12.18-12.37	12.18-12.37
Crude Protein		20.0	19.0	18.0	17.0	17.0
Lysine		1.05	0.98	0.88	0.76	0.78
Methionine		0.47	0.44	0.40	0.36	0.38
Met + Cystine		0.74	0.74	0.67	0.59	0.66
Threonine		0.69	0.66	0.60	0.52	0.55
Tryptophan		0.18	0.18	0.17	0.15	0.16
Arginine		1.12	1.05	0.94	0.81	0.83
Isoleucine		0.74	0.71	0.65	0.57	0.62
Valine		0.76	0.73	0.69	0.61	0.66

(from W36 Hy-line, 2012)

POULTRY



RECOMMENDATIONS FOR LAYING HENS

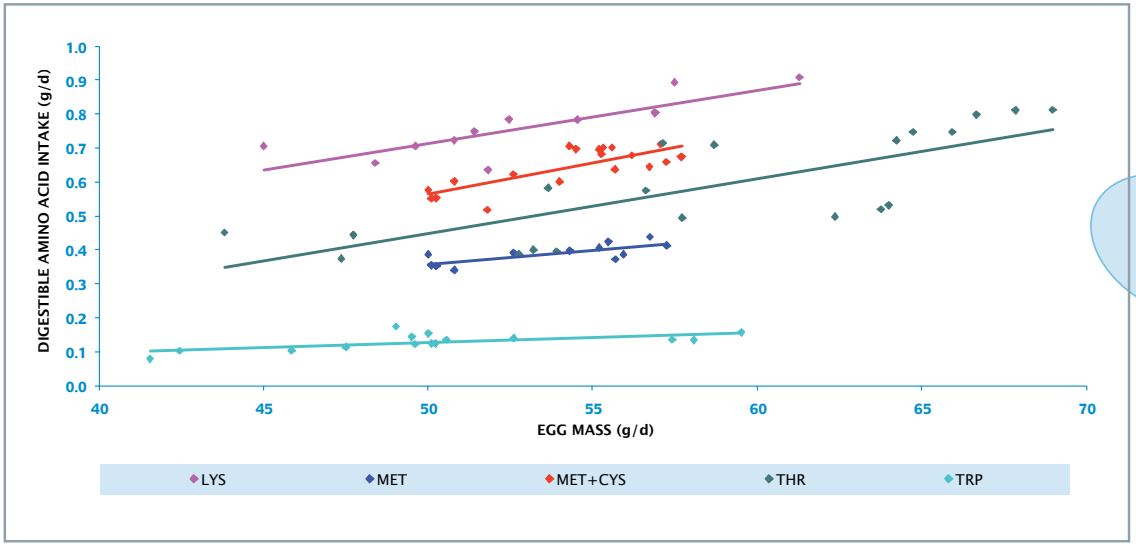
DIGESTIBLE AMINO ACID REQUIREMENTS IN G/D:

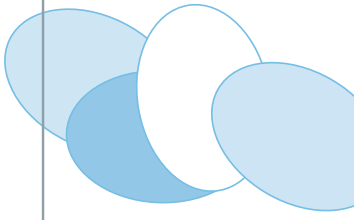
Amino acid recommendations are given on the basis of standardized ileal digestible amino acids (SID). Modelling equations are available for lysine, methionine, methionine + cystine, threonine and tryptophan.

Table 7: Modelling equations for predicting digestible amino acid requirements (y, g/d) of laying hens according to egg mass (x, g/d).

Criterion	EM (g/d)	
	Equation	R^2
Lysine	y=0.0156 x-0.0673	0.71
Methionine	y=0.0083 x-0.0550	0.61
Met + Cystine	y=0.0184 x-0.3531	0.62
Threonine	y=0.0161 x-0.3570	0.62
Tryptophan	y=0.0030 x-0.0194	0.40

Figure 4: Minimum digestible amino acid intake (g/d) for optimal egg mass (g/d) covering various periods from 21 to 85 weeks of age: lysine, 12 trials; methionine, 13 trials; methionine + cystine, 19 trials; threonine, 21 trials and tryptophan, 15 trials.





IDEAL PROTEIN PROFILES:

For arginine, isoleucine, valine, histidine, leucine and phenylalanine + tyrosine, the AA/lysine ratios were obtained from an average of profiles taken from published literature for layers (Table 8).

Table 8: Ideal digestible amino acid profiles used to complement the layer model.

	Bregendahl *et al.* (2008)	Rostagno (2011)
Lysine	100	100
Arginine	-	100
Isoleucine	79	76
Valine	93	95
Histidine	-	29
Leucine	-	122
Phe + Tyrosine	-	118

As an example, the digestible amino acid recommendations for laying hens producing an egg mass of 58 g per day with different daily feed intakes were estimated using the equation models.

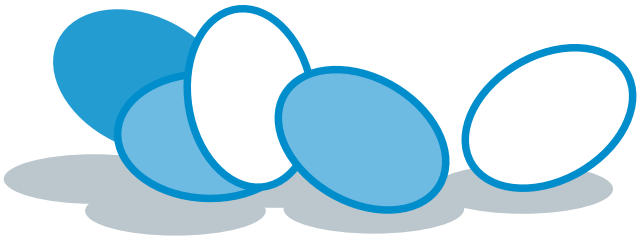
Table 9: Calculated digestible amino acid recommendations for laying hens producing an egg mass of 58 g per day at different daily feed intakes.

		EM (in mg/d)	Daily feed intake for 58 g/d egg mass (g)				
ME[1]	kcal/d	335					
	MJ/d	1.4					
Lysine		58 g/d	80	90	100	110	120
		838	1.05	0.93	0.84	0.76	0.70
Methionine		426	0.53	0.47	0.43	0.39	0.36
Met + Cystine		714	0.89	0.79	0.71	0.65	0.60
Threonine		577	0.72	0.64	0.58	0.52	0.48
Tryptophan		155	0.19	0.17	0.15	0.14	0.13
Arginine		838	1.05	0.93	0.84	0.76	0.70
Isoleucine		662	0.83	0.74	0.66	0.60	0.55
Valine		787	0.98	0.87	0.79	0.72	0.66
Histidine		243	0.30	0.27	0.24	0.22	0.20
Leucine		1022	1.28	1.14	1.02	0.93	0.85
Phe + Tyrosine		988	1.24	1.10	0.99	0.90	0.82

[1] The ME recommendation is derived from the following equation: ME per hen daily = $W^{0.75}$ (173 - 1.95T) + 5.5 △W+ 2.07 EE (NRC, 1981), where W = body weight (kg), T = ambient temperature (°C), △W = change in body weight (g/day), and EE = daily egg mass (g). Temperature of 22°C, body weight of 2kg, egg weight of 58 g, no change in body weight was used in calculations.

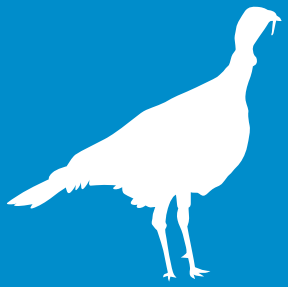
Table 10: Ideal digestible amino acid profiles for laying hens (%).

Lysine[1]	100
Methionine[1]	51
Met + Cystine[1]	85
Threonine[1]	69
Tryptophan[1]	18
Arginine[2]	100
Isoleucine[2]	79
Valine[2]	94
Histidine[2]	29
Leucine[2]	122
Phe + Tyrosine[2]	118



[1] DAA/lysine ratio based on regressions of optimal performance.
[2] DAA/lysine ratio based on published ideal-protein profiles.

RECOMMENDATIONS FOR TURKEYS



DIGESTIBLE AMINO ACID REQUIREMENTS IN G/D:

Amino acid recommendations are given on the basis of standardized ileal digestible amino acids (SID). Modelling equations are available only for lysine, methionine + cystine and threonine.

Table 11: Modelling equations for predicting digestible amino acid requirements (y, g/d) of turkeys based on average daily gain and feed conversion ratio (x, g/d).

	ADG		FCR	
	Equation	**R^2**	**Equation**	**R^2**
Lysine	y=0.0253 x-0.1747	0.93	y=0.0237 x-0.0807	0.95
Met + Cystine	y=0.0178 x-0.1526	0.87	y=0.0180 x-0.1609	0.89
Threonine	y=0.0144 x-0.1227	0.96	y=0.0142 x-0.0925	0.96

Figure 5: Minimum digestible amino acid intake (g/d) for optimal weight gain (g/d) of turkeys covering various periods from 1 to 22 weeks using medium and heavy strains: lysine, 30 trials; methionine + cystine, 18 trials and threonine, 11 trials.

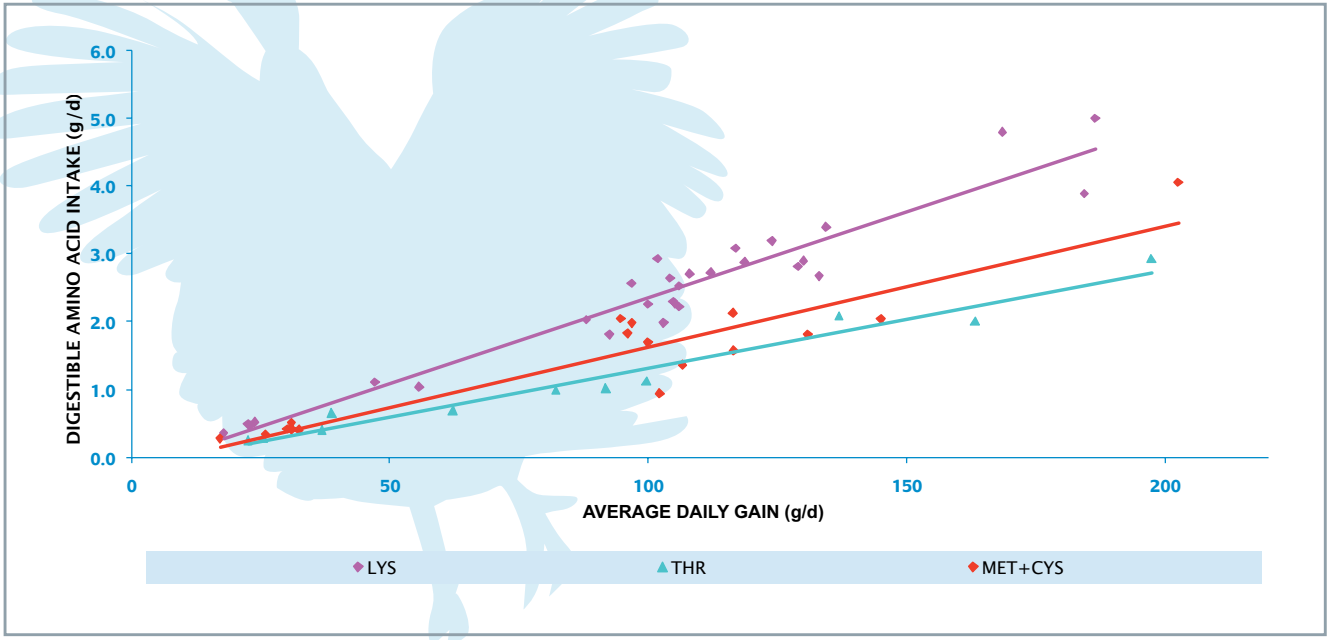
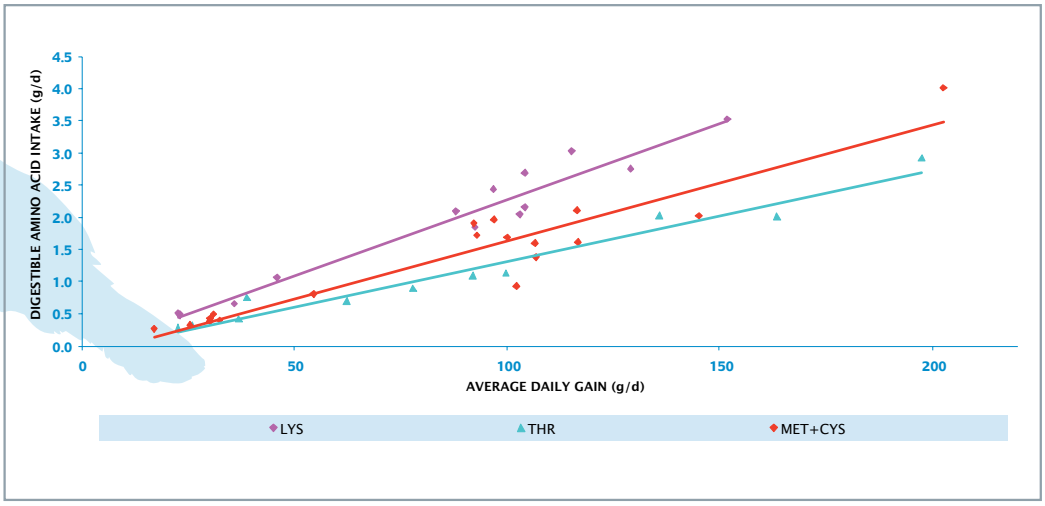


Figure 6: Minimum digestible amino acid intake (g/d) for optimal feed conversion ratio (g/g) of turkeys covering various periods from 1 to 22 weeks using medium and heavy strains: lysine, 13 trials; methionine + cystine, 18 trials and threonine, 11 trials.



IDEAL PROTEINS PROFILES:

For other amino acids, the AA/lysine ratios were obtained from the ideal-protein model given in the feeding guidelines for Nicholas and BUT heavy lines (Aviagen Turkeys, 2012), and from the broiler profile for leucine, histidine and phenylalanine + tyrosine.

Table 12: Ideal digestible amino acid profiles used to complement the turkey model (%).

Age	Male	1-21d	22-42d	43-63d	64-84d	85-105d	106-126d	127-147d
	Female	1-21d	22-42d	43-56d	57-70d	71-84d	85-98d	99-126d
Lysine		100	100	100	100	100	100	100
Methionine		36	36	37	38	38	41	43
Tryptophan		14	16	16	16	18	19	20
Arginine		102	103	103	103	103	104	105
Isoleucine		61	61	62	62	63	64	65
Valine		67	68	69	70	71	72	74

(from Aviagen Turkeys, 2012)

As an example, the digestible amino acid recommendations for heavy-strain male and female turkeys (BIG 9) were estimated using the equation models and the growth performance published by the breeding company (Aviagen Group); ADG and DFI were calculated as being the average for each period.

Table 13a: Example of calculated digestible amino acid recommendations for turkey toms (% diet).

MALE		Age							
		1-3wk	4-6wk	7-9wk	10-12wk	13-15wk	16-18wk	19-21wk	22-24wk
ME[1]	kcal/kg	2 868	2 964	2 964	3 060	3 084	3 155	3 155	3 180
	MJ/kg	12.0	12.4	12.4	12.8	12.9	13.2	13.2	13.3
Performance of reference[2]	ADG	28	53	82	106	123	133	139	142
	DFI	34	83	145	206	262	314	365	422
Lysine	ADG	1.56	1.40	1.31	1.22	1.12	1.02	0.91	0.81
	FCR	1.70	1.41	1.28	1.18	1.08	0.98	0.88	0.78
Methionine	ADG	0.56	0.50	0.48	0.46	0.42	0.42	0.39	0.35
	FCR	0.61	0.51	0.48	0.45	0.41	0.40	0.38	0.33
Met + Cystine	ADG	1.01	0.95	0.90	0.84	0.77	0.71	0.63	0.56
	FCR	1.00	0.95	0.91	0.85	0.78	0.71	0.64	0.57
Threonine	ADG	0.82	0.77	0.73	0.68	0.63	0.57	0.51	0.46
	FCR	0.89	0.79	0.74	0.68	0.63	0.57	0.51	0.46
Tryptophan	ADG	0.22	0.22	0.21	0.19	0.20	0.19	0.18	0.16
	FCR	0.24	0.23	0.21	0.19	0.19	0.19	0.18	0.16
Arginine	ADG	1.59	1.44	1.35	1.25	1.15	1.06	0.96	0.85
	FCR	1.74	1.46	1.32	1.21	1.11	1.02	0.92	0.82
Isoleucine	ADG	0.95	0.86	0.81	0.75	0.70	0.65	0.59	0.53
	FCR	1.04	0.86	0.80	0.73	0.68	0.63	0.57	0.51
Valine	ADG	1.04	0.95	0.90	0.85	0.79	0.73	0.67	0.60
	FCR	1.14	0.96	0.89	0.83	0.77	0.70	0.65	0.58
Histidine	ADG	0.58	0.52	0.48	0.45	0.41	0.38	0.34	0.30
	FCR	0.63	0.52	0.48	0.44	0.40	0.36	0.32	0.29
Leucine	ADG	1.70	1.53	1.43	1.32	1.22	1.11	0.99	0.88
	FCR	1.86	1.54	1.40	1.28	1.18	1.07	0.96	0.85
Phe + Tyrosine	ADG	1.79	1.61	1.51	1.40	1.29	1.17	1.05	0.93
	FCR	1.96	1.63	1.48	1.36	1.24	1.12	1.01	0.90

[1] Aviagen Turkeys (2009)
[2] BIG 9 (2012)

Table 13b: Example of calculated digestible amino acid recommendations for turkey hens (% diet).

FEMALE		Age						
		1-3wk	4-6wk	7-9wk	10-12wk	13-15wk	16-18wk	19-20wk
ME[1]	kcal/kg	2 868	2 964	2 964	3 060	3 084	3 155	3 155
	MJ/kg	12.0	12.4	12.4	12.8	12.9	13.2	13.2
Performance of reference[2]	ADG	24	43	64	79	88	92	92
	DFI	30	70	119	167	211	249	274
Lysine	ADG	1.49	1.31	1.21	1.10	0.98	0.87	0.79
	FCR	1.67	1.35	1.20	1.08	0.96	0.85	0.77
Methionine	ADG	0.53	0.47	0.45	0.42	0.37	0.36	0.32
	FCR	0.60	0.49	0.44	0.41	0.36	0.35	0.31
Met + Cystine	ADG	0.95	0.88	0.83	0.75	0.67	0.60	0.54
	FCR	0.93	0.88	0.83	0.76	0.68	0.60	0.55
Threonine	ADG	0.77	0.71	0.67	0.61	0.55	0.49	0.44
	FCR	0.85	0.75	0.68	0.62	0.55	0.49	0.44
Tryptophan	ADG	0.21	0.21	0.19	0.19	0.18	0.18	0.15
	FCR	0.23	0.22	0.19	0.17	0.17	0.16	0.15
Arginine	ADG	1.52	1.37	1.25	1.13	1.01	0.90	0.82
	FCR	1.70	1.39	1.24	1.11	0.98	0.88	0.80
Isoleucine	ADG	0.91	0.80	0.75	0.68	0.62	0.56	0.50
	FCR	1.02	0.82	0.75	0.67	0.60	0.54	0.49
Valine	ADG	1.00	0.89	0.83	0.77	0.69	0.63	0.57
	FCR	1.12	0.92	0.83	0.75	0.68	0.61	0.55
Histidine	ADG	0.55	0.49	0.45	0.41	0.36	0.32	0.29
	FCR	0.62	0.50	0.44	0.40	0.35	0.31	0.28
Leucine	ADG	1.62	1.43	1.32	1.20	1.07	0.95	0.86
	FCR	1.82	1.47	1.31	1.17	1.04	0.92	0.84
Phe + Tyrosine	ADG	1.71	1.51	1.39	1.26	1.13	1.00	0.91
	FCR	1.92	1.55	1.38	1.24	1.10	0.97	0.88

[1] Aviagen Turkeys (2009)
[2] BIG 9 (2012)

Table 14: Ideal digestible amino acid profiles for turkeys (%).

	Age							
	1-3wk	4-6wk	7-9wk	10-12wk	13-15wk	16-18wk	19-21wk	22-24wk
Lysine[1]	100	100	100	100	100	100	100	100
Methionine[2]	36	36	37	38	38	41	42	43
Met + Cystine[1]	64	67	69	70	70	71	71	71
Threonine[1]	52	55	56	57	57	57	57	57
Tryptophan[2]	14	16	16	16	18	19	20	20
Arginine[2]	102	103	103	103	103	104	105	105
Isoleucine[2]	61	61	62	62	63	64	65	65
Valine[2]	67	68	69	70	71	72	73	74
Histidine[2]	37	37	37	37	37	37	37	37
Leucine[2]	109	109	109	109	109	109	109	109
Phe + Tyrosine[2]	115	115	115	115	115	115	115	115

[1] Based on regressions on optimal performance
[2] Based on published ideal protein profiles

RECOMMENDATIONS FOR DUCKS

Because of the limited number of scientific publications, it has not been possible to model the amino acid requirements of ducks. The following requirements have been adapted from the recommendations given by duck producers.

Table 15: Total amino acid recommendations for Pekin and Muscovy ducks (% diet).

		Pekin duck[1]		Muscovy duck[2]		
		Starter	**Grower-finisher**	**Starter**	**Grower**	**Finisher**
Age		**0-2wk**	**2wk to slaughter**	**0-3wk**	**4-7wk**	**8-12wK**
ME	kcal/kg	2 900-2 950	3 050-3 150	2 850-2 900	2 900-3 100	3 000-3 200
	MJ/kg	12.14-12.35	12.77-13.19	11.93-12.14	12.14-12.98	12.56-13.40
Crude Protein (%)		20	17-19	19-22	17-19	15-18
Lysine		1.00	0.80	0.95	0.85	0.75
Methionine		0.50	0.40	0.45	0.40	0.30
Met + Cystine		0.85	0.70	0.85	0.65	0.60
Threonine		0.75	0.60	0.75	0.60	0.50
Tryptophan		0.23	0.16	0.23	0.16	0.16

[1] from Grimaud Frères Sélection, 2010b
[2] from Grimaud Frères Sélection, 2010a

RECOMMENDATIONS FOR PIGLETS AND PIGS

DIGESTIBLE AMINO ACID REQUIREMENTS IN G/D:

Amino acid recommendations are given on the basis of standardized ileal digestible amino acids (SID). Modelling equations are available for lysine, methionine, methionine + cystine, threonine, tryptophan, isoleucine and valine, using a single model for piglets and pigs.

Table 16: Modelling equations for predicting digestible amino acid requirements (y, g/d) of pigs based on the average daily gain and feed conversion ratio (x, g/d).

	ADG		FCR	
	Equation	**R^2**	**Equation**	**R^2**
Lysine	y=0.0194 x-0.3466	0.92	y=0.0198 x-0.4686	0.93
Methionine	y=0.0055 x-0.0719	0.83	y=0.0062 x-0.0397	0.74
Met + Cystine	y=0.0112 x-0.3969	0.95	y=0.0115 x-0.4965	0.94
Threonine	y=0.0124 x-0.8480	0.84	y=0.0115 x+0.0609	0.85
Tryptophan	y=0.0027 x+0.1978	0.53	y=0.0028 x+0.1030	0.61
Isoleucine	y=0.0120 x-1.1696	0.94	y=0.0132 x-1.3668	0.95
Valine	y=0.0136 x-1.0475	0.93	y=0.0125 x-0.2315	0.90

Figure 7: Minimum digestible amino acid intake (g/d) for optimal weight gain (g/d) covering various bodyweight ranges from 3 to 115kg: lysine, 66 trials; methionine, 23 trials; methionine + cystine, 51 trials; threonine, 16 trials; tryptophan, 30 trials; isoleucine, 17 trials and valine, 13 trials.

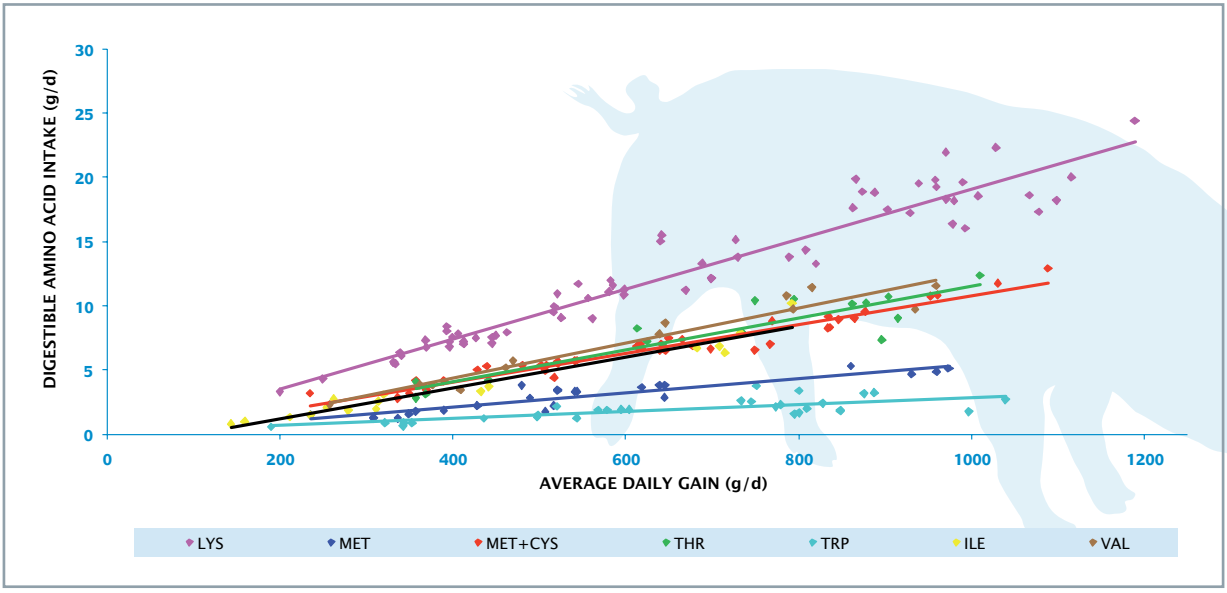
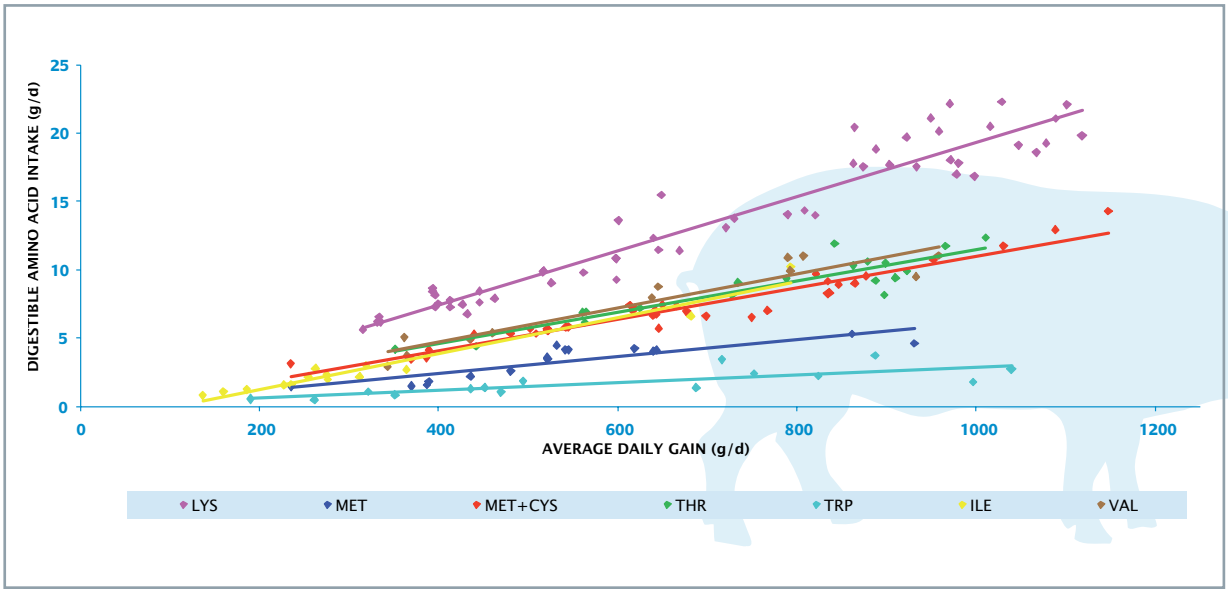


Figure 8: Minimum digestible amino acid intake (g/d) for optimal feed conversion ratio (g/g) covering various bodyweight ranges from 3 to 115kg: lysine, 66 trials; methionine, 23 trials; methionine + cystine, 51 trials; threonine, 16 trials; tryptophan, 30 trials; isoleucine, 17 trials and valine, 13 trials.



IDEAL PROTEIN PROFILES:

For arginine, histidine, leucine and phenylalanine + tyrosine, the amino acid / lysine ratios were taken from NRC (2012), being the ratio of the standardized ileal digestible amino acid requirements with digestible lysine.

Table 17: Ideal digestible amino acid profiles used to complement the pig model (%).

	Body weight range						
	5-7kg	**7-11kg**	**11-25kg**	**25-50kg**	**50-75kg**	**75-100kg**	**100-135kg**
Lysine	100	100	100	100	100	100	100
Arginine	45	45	46	46	46	45	46
Histidine	35	34	34	35	34	34	34
Leucine	100	100	100	101	100	101	102
Phe + Tyrosine	92	93	93	94	94	95	95

(adapted from NRC, 2012)

As an example, the digestible amino acid recommendations for pigs following the NRC (2012) growth curve were estimated using the equation models.

Table 18: Calculated digestible amino acid recommendations for growing pigs according to bodyweight and growth performance (% diet).

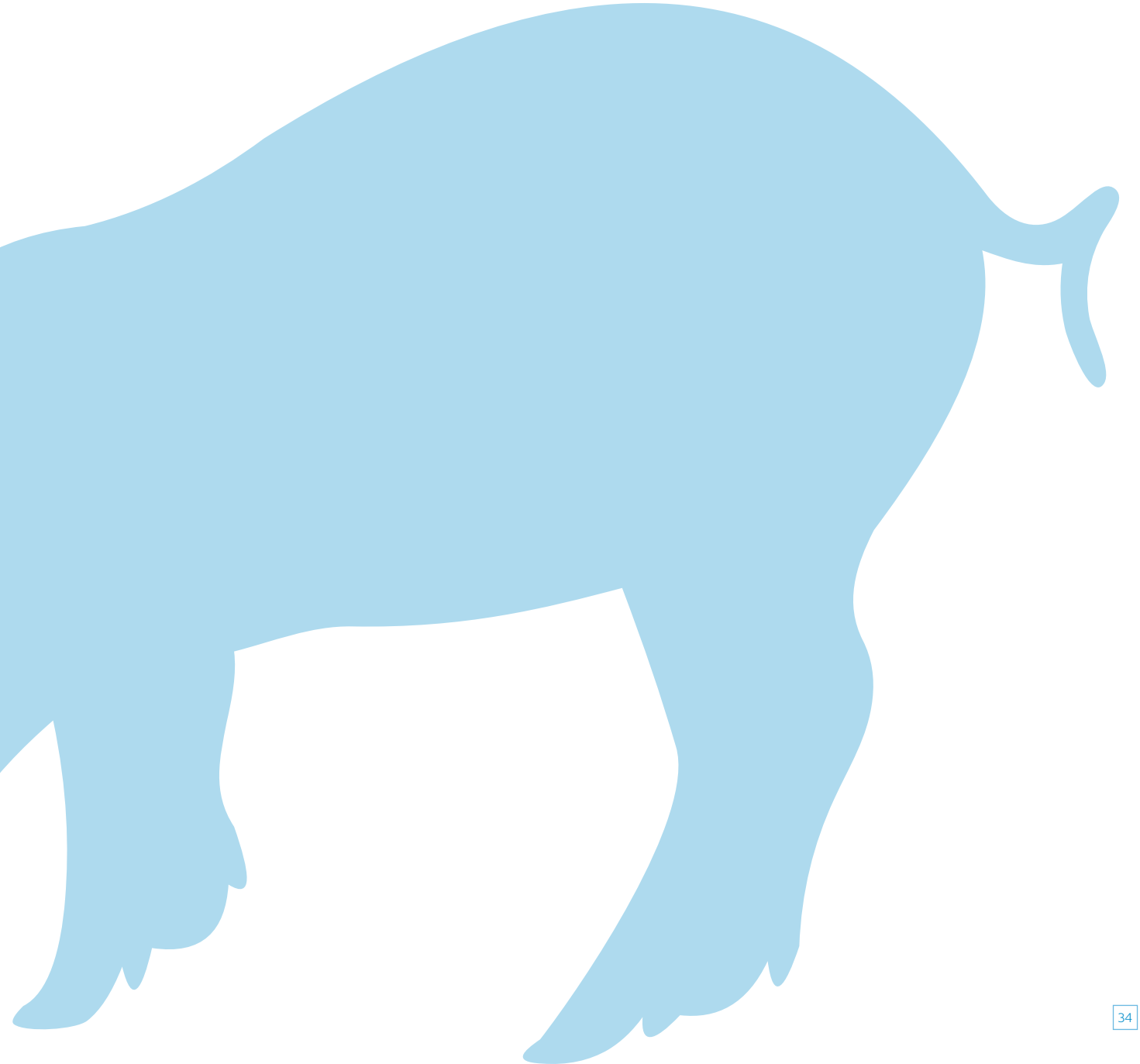
		Body weight range						
		5-7kg	**7-11kg**	**11-25kg**	**25-50kg**	**50-75kg**	**75-100kg**	**100-135kg**
Performance of reference[1]	ADG	210	335	585	758	900	917	867
	DFI	266	468	905	1 503	2 118	2 504	2 786
NE[2]	kcal/kg	2 448	2 448	2 412	2 475	2 475	2 475	2 475
	MJ/kg	10.25	10.25	10.10	10.36	10.36	10.36	10.36
Lysine	ADG	1.40	1.31	1.22	0.96	0.81	0.70	0.59
	FCR	1.39	1.32	1.23	0.97	0.82	0.71	0.60
Methionine	ADG	0.41	0.38	0.35	0.27	0.23	0.20	0.17
	FCR	0.47	0.43	0.40	0.31	0.26	0.23	0.19
Met + Cystine	ADG	0.74	0.72	0.68	0.54	0.46	0.39	0.33
	FCR	0.72	0.72	0.69	0.55	0.47	0.40	0.34
Threonine	ADG	0.66	0.71	0.71	0.57	0.49	0.42	0.36
	FCR	0.93	0.84	0.75	0.58	0.49	0.42	0.36
Tryptophan	ADG	0.29	0.24	0.20	0.15	0.12	0.11	0.09
	FCR	0.26	0.22	0.19	0.15	0.12	0.11	0.09
Arginine	ADG	0.63	0.59	0.56	0.44	0.37	0.31	0.27
	FCR	0.62	0.59	0.56	0.45	0.38	0.32	0.28
Isoleucine	ADG	0.51	0.61	0.65	0.53	0.45	0.39	0.33
	FCR	0.53	0.65	0.70	0.57	0.50	0.43	0.36
Valine	ADG	0.68	0.75	0.76	0.62	0.53	0.46	0.39
	FCR	0.90	0.84	0.78	0.62	0.52	0.45	0.38
Histidine	ADG	0.49	0.45	0.41	0.33	0.27	0.24	0.20
	FCR	0.49	0.45	0.42	0.34	0.28	0.24	0.20
Leucine	ADG	1.40	1.31	1.22	0.96	0.81	0.70	0.60
	FCR	1.39	1.32	1.23	0.98	0.82	0.71	0.61
Phe + Tyrosine	ADG	1.29	1.22	1.13	0.90	0.76	0.66	0.56
	FCR	1.28	1.22	1.14	0.91	0.77	0.67	0.57

[1, 2] NRC (2012)

Table 19: Ideal digestible amino acid profiles of growing pigs according to bodyweight (%).

	Body weight range						
	5-7kg	**7-11kg**	**11-25kg**	**25-50kg**	**50-75kg**	**75-100kg**	**100-135kg**
Lysine[1]	100	100	100	100	100	100	100
Methionine[1]	32	31	30	30	30	30	30
Met + Cystine[1]	52	54	56	56	57	57	57
Threonine[1]	57	59	60	60	60	60	60
Tryptophan[1]	20	17	16	15	15	15	15
Arginine[2]	45	45	46	46	46	45	46
Isoleucine[1]	37	48	55	57	58	59	58
Valine[1]	57	61	63	64	64	64	64
Histidine[2]	35	34	34	35	34	34	34
Leucine[2]	100	100	100	101	100	101	102
Phe + Tyrosine[2]	92	93	93	94	94	95	95

[1] Based on regressions on optimal performance
[2] Based on published ideal protein profiles



SWINE

RECOMMENDATIONS FOR GESTATING SOWS

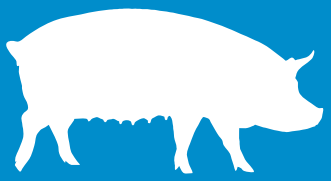


Table 20: Standardized digestible amino acid recommendations for gestating sows (% diet).

		Parity							
		1		2		3		4	
Days of gestation		**<90**	**>90**	**<90**	**>90**	**<90**	**>90**	**<90**	**>90**
DFI (g/d)		2 000	2 400	2 100	2 500	2 100	2 500	2 000	2 400
NE	kcal/kg	2 520							
	MJ/kg	10.55							
Lysine		0.52	0.69	0.44	0.61	0.37	0.30	0.32	0.48
Methionine		0.15	0.20	0.12	0.17	0.15	0.15	0.09	0.14
Met + Cystine		0.34	0.45	0.29	0.34	0.26	0.36	0.30	0.34
Threonine		0.37	0.48	0.30	0.30	0.29	0.39	0.28	0.37
Tryptophan		0.09	0.13	0.08	0.12	0.07	0.11	0.07	0.11
Arginine		0.28	0.37	0.23	0.20	0.19	0.28	0.17	0.25
Isoleucine		0.30	0.36	0.25	0.20	0.20	0.27	0.20	0.25
Valine		0.37	0.49	0.20	0.30	0.28	0.39	0.26	0.36
Histidine		0.18	0.22	0.15	0.19	0.13	0.16	0.11	0.15
Leucine		0.47	0.65	0.47	0.57	0.35	0.51	0.32	0.47
Phe + Tyrosine		0.50	0.66	0.30	0.58	0.37	0.51	0.33	0.47

(adapted from NRC, 2012)

SWINE

RECOMMENDATIONS FOR LACTATING SOWS

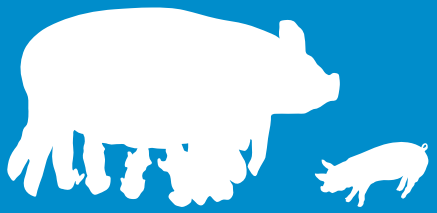


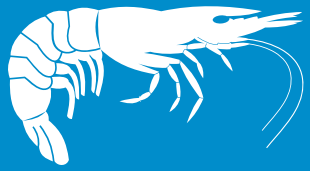
Table 21: Standardized digestible amino acid recommendations for lactating sows (% diet).

		Parity 1			Parity 2 or more		
ADG of the litter (g/d)		2 090	2 530	2 970	2 185	2 645	3 105
DFI (g/d)		5 700	5 700	5 700	6 300	6 300	6 300
NE	kcal/kg	2 520					
	MJ/kg	10.55					
Lysine		0.75	0.81	0.87	0.72	0.78	0.84
Methionine		0.20	0.21	0.23	0.19	0.21	0.22
Met + Cystine		0.39	0.43	0.47	0.38	0.41	0.45
Threonine		0.47	0.51	0.55	0.46	0.49	0.53
Tryptophan		0.14	0.15	0.17	0.13	0.15	0.16
Arginine		0.43	0.40	0.46	0.42	0.43	0.45
Isoleucine		0.41	0.45	0.49	0.40	0.43	0.47
Valine		0.64	0.69	0.74	0.61	0.66	0.71
Histidine		0.30	0.32	0.34	0.29	0.31	0.33
Leucine		0.83	0.92	1.00	0.80	0.88	0.96
Phe + Tyrosine		0.83	0.91	0.99	0.80	0.87	0.95

(adapted from NRC, 2012)

AQUACULTURE

RECOMMENDATIONS FOR FISH AND SHRIMP



Despite the growing interest in aquaculture, very little information is available on amino acid digestibility and requirements for these animal species. As a consequence, the requirements listed here are only expressed on a total amino acid basis.

Table 22: Total amino acid recommendations for fish and shrimp (% diet).

	Atlantic salmon	Common carp	Tilapia	Channel catfish	Asian sea bass	European sea bass	Japanese flounder	Tiger shrimp
DE (kcal/kg)	4 400	3 200	3 400	3 400	4 200	4 000	4 000	3 000
DP (%)	36	32	29	29	38	40	40	34
Lysine	2.4	2.2	1.6	1.6	2.1	2.2	2.6	2.1
Methionine	0.7	0.7	0.7	0.6	0.8	NA	0.9	0.7
Met + Cystine	1.1	1.0	1.0	0.9	1.2	1.1	NA	1.0
Threonine	1.1	1.5	1.1	0.7	NA	1.2	NA	1.4
Tryptophan	0.3	0.3	0.3	0.2	NA	0.3	NA	0.2
Arginine	1.8	1.7	1.2	1.2	1.8	1.8	2.0	1.9
Isoleucine	1.1	1.0	1.0	0.8	NA	NA	NA	1.0
Valine	1.2	1.4	1.5	0.8	NA	NA	NA	NA
Histidine	0.8	0.5	1.0	0.6	NA	NA	NA	0.8
Leucine	1.5	1.4	1.9	1.3	NA	NA	NA	1.7
Phe + Tyrosine	1.8	2.0	1.6	1.6	NA	NA	NA	NA
Taurine	NA	NA	NA	NA	NA	0.2	NA	NA

(adapted from NRC, 2011)

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