Amino acid requirement of growing and finishing pigs

C.M.C. van der Peet-Schwering, P. Bikker

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C.M.C. van der Peet-Schwering[1], P. Bikker[1]

[1] Wageningen Livestock Research

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Summary.
In the Netherlands, AA recommendations for pigs are published by the Centraal Veevoederbureau (CVB, Central Bureau for Livestock Feeding). The CVB recommendations, however, have not been updated since 1996. Because the genetic capacity and therefore daily gain and feed conversion ratio of the growing and finishing pigs have been improved in the last 20 years and will probably further improve in the next years, the amino acid recommendations from 1996 had to be updated. The updated AA requirements in starter, grower and finisher diets for the current and future growing and finishing pigs (boars, gilts and barrows) are presented in this report.

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P.O. Box 338, 6700 AH Wageningen, The Netherlands, T +31 (0)317 48 39 53,
E info.livestockresearch@wur.nl, www.wur.nl/livestock-research. Wageningen Livestock Research is part of Wageningen University & Research.

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Foreword

The research “Amino acid requirement of growing and finishing pigs” was conducted by Wageningen Livestock Research as part of the Public Private Partnership “Feed4Foodure”, and was funded by Vereniging Diervoederonderzoek Nederland (VDN) and the Ministry of Agriculture, Nature and Food Quality (LNV). The authors thank VDN and LNV for their support, and the members of the Cluster “Swine” of VDN for their valuable and inspiring contribution to the research.

The authors:
Carola van der Peet-Schwering and Paul Bikker

Summary

Knowledge about the amino acid (AA) requirements and about the response of pigs to the amino acid supply is essential in formulating diets for growing and finishing pigs. A deficient supply of AA will reduce the performance of pigs whereas an oversupply will increase the nitrogen excretion. In the Netherlands, AA recommendations for pigs are published by the Centraal Veevoederbureau (CVB). The CVB recommendations, however, have not been updated since 1996. Because the genetic capacity and therefore daily gain and feed conversion ratio of the growing and finishing pigs have been improved in the last 20 years and will probably further improve in the next years, the amino acid recommendations from 1996 had to be updated. With help of the pig model InraPorc (Van Milgen et al., 2008) and based on literature data, we predicted the AA requirements for current growing and finishing pigs (boars, gilts and barrows) and for future growing and finishing pigs. We supposed that the daily gain of the future growing and finishing pigs is 10% higher than the daily gain of the current growing and finishing pigs and is realized by a 10% higher feed intake or a 10% improved feed conversion ratio. The standardized ileal digestible (SID) lysine requirement was predicted with InraPorc (Van Milgen et al., 2008). Because InraPorc is based on fixed ratios between SID lysine and other essential AA, that cannot be changed by the user of the model, it was decided to estimate the requirement of the other essential AA, relative to lysine, based on literature data of the last 10 years. The updated AA requirements in starter, grower and finisher diets for the current and future growing and finishing pigs (boars, gilts and barrows) are presented in chapter 5 of this report. The SID lysine recommendations are higher for boars than for gilts and in general higher for gilts than for barrows. Besides they are mostly higher in the future pigs than in the current pigs.

1 Introduction

Knowledge about the amino acid (AA) requirements and about the response of pigs to the amino acid supply is essential in formulating diets for growing and finishing pigs. A deficient supply of AA will reduce the performance of pigs whereas an oversupply will increase the nitrogen excretion (Van Milgen and Dourmad, 2015). In the Netherlands, AA recommendations for pigs are published by the Centraal Veevoederbureau (CVB). Besides, some feed companies use their own confidential recommendations.
The CVB recommendations have not been updated since 1996. In 1996, the CVB has reformulated the AA recommendations of growing and finishing pigs, based on actual knowledge at that time and with help of the growth model TMV (CVB Documentation report nr. 14, 1996). Since then, these recommendations are used in the Netherlands for optimizing diets for growing and finishing pigs.
AA requirements were expressed as apparent ileal digestible (AID) amino acid per EW. In 2015, a new formula to calculate the net energy value (NE_{2015} or EW_{2015}; EW_{2015} = NE_{2015} (in MJ) / 8.8 MJ) of feed ingredients for growing and finishing pigs was introduced (Blok et al., 2015). With this new formula, the NE_{2015} (and EW_{2015}) of ingredients (with the exception of pure fats) and diets is higher than with the former NE formula which was published in 1993. This results in a lower AID amino acid requirement per EW_{2015} than per the former EW (CVB, 2016a).
It is now common practice to express AA requirements on a standardized ileal digestible (SID) basis instead of on a AID basis (Van Milgen and Dourmad, 2015). Standardization means that the AID is corrected for basal endogenous losses, which are assumed to depend on dry matter intake (Van Milgen and Dourmad, 2015).
In Table 1, the current recommended AID lysine level in starter diet, grower diet and finisher diet in g/EW (1996) and in g/EW_{2015} (2016a) is presented. Moreover, the recommended standardized (SID) lysine level in these diets, using the composition of basal endogenous protein as published by CVB (2016b) for recalculating AID to SID, is presented.

Table 1 *Apparent ileal digestible lysine (AID Lys) per EW and per EW_{2015} and standardized ileal digestible lysine (SID Lys) per EW_{2015} as recommended by the CVB (1996, 2016a and 2016b)*

	AID Lys/EW	AID Lys/EW_{2015}	SID Lys/EW_{2015}
Starter diet (25-40 kg)	8.3	8.0	8.3
Grower diet (40-70 kg)	7.1	6.8	7.1
Finisher diet (70-110 kg)	5.9	5.7	6.0
Finisher diet (40-110 kg)	6.7	6.5	6.8

Because the genetic capacity and therefore daily gain and feed conversion ratio of the growing and finishing pigs have been improved in the last 20 years and will probably further improve in the next years, the amino acid recommendations from 1996 have to be updated.

Lysine is in general the first limiting amino acid in diets for growing and finishing pigs. It is common practice to first define the adequate lysine level in the diet and express the level of other essential AA as a ratio to lysine based on the concept of “ideal protein”. Because AA requirements change during growth and differs between sexes and genotypes, modelling approaches have been used to predict the requirements (Van Milgen and Dourmad, 2015). Besides, with models the AA requirement of future pigs can be predicted by using assumptions about the future pigs. The French InraPorc model (Van Milgen et al., 2008) and the American NRC model (NRC, 2012) are two available models that can be used to calculate the AA requirements of growing and finishing pigs.

With help of the pig model InraPorc (Van Milgen et al., 2008) and based on literature data, we predicted the AA requirements for current growing and finishing pigs (boars, gilts and barrows) and for future growing and finishing pigs. The SID lysine requirement is predicted with InraPorc (Van Milgen et al., 2008). Because InraPorc is based on fixed ratios between SID lysine and other essential AA, that cannot be changed by the user of the model, it was decided to estimate the requirement of the other essential AA, relative to lysine, based on literature data of the last 10 years.
The proposed AA requirements for the current and future growing and finishing pigs are presented in this report.

2 Material and methods

2.1 Brief description of InraPorc

The brief description of InraPorc is adapted from Van Milgen et al. (2008). InraPorc is based on a factorial approach. The intake of net energy (NE) and SID AA and the potential protein deposition of the pig are the main factors in the model that determine the partitioning of NE between protein deposition (PD) and lipid deposition (LD). NE supply is used for maintenance, physical activity and the cost of protein deposition. The remainder of NE will be used for lipid deposition. The response of PD to the energy supply is described by s curvilinear-plateau function, which is parameterised by PD at ad libitum NE intake and the marginal PD at this intake (see Figure 1). The marginal PD is the change in PD due to a change in NE intake.

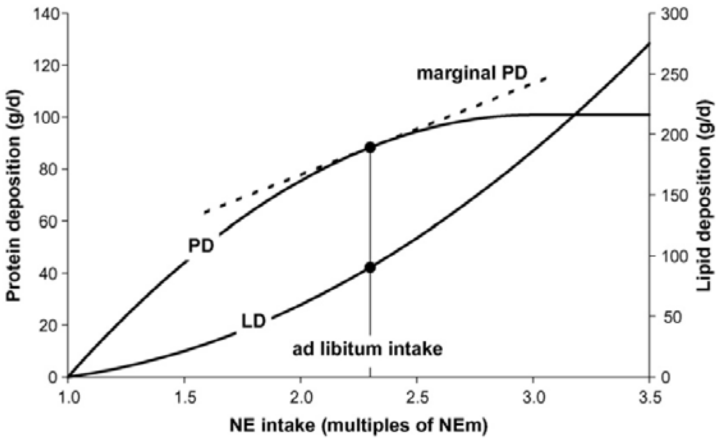


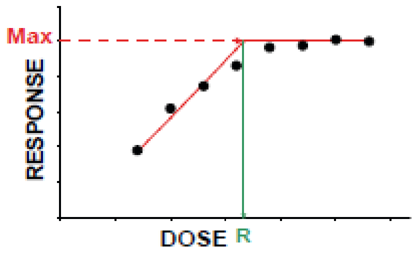
Figure 1 *Protein (PD) and lipid deposition (LD) at ad libitum intake and the response curves of PD and LD to a changing energy supply (solid lines) (Van Milgen et al., 2008)*

The potential protein deposition is a phenotypic trait and is defined as the PD at ad libitum feeding. Ad libitum feed intake is a model input factor and is calculated as a function of body weight. The potential PD is defined by a Gompertz function and is described by 3 model parameters: the initial protein mass (which is strongly related to the initial body weight), the average protein deposition over the growing period (related to the average daily gain) and a “precocity” parameter describing if the animal is early- or late-maturing. Based on the PD curve and the amino acid composition of deposited protein, AA deposition curves can be determined.
The actual PD is the minimum of the potential PD and the PD allowed by the amino acid supply. In InraPorc twelve (semi-) essential AA and the total nitrogen supply are considered to calculate PD. For each amino acid, the PD allowed by the supply of SID AA is calculated by subtracting the maintenance amino acid requirement from the SID amino acid intake, by multiplying this with the maximum efficiency of amino acid utilisation and dividing the resulting value by the amino acid content of body protein. The maximum efficiency of amino acid utilisation is considered a constant value and is calculated from the ideal amino acid profile and the composition of body protein and components of maintenance (see Table 2 in Van Milgen et al., 2008 and Table 2 in Van Milgen and Dourmad, 2015). The maximum efficiency of amino acid utilisation is not the same for all AA. The maximum efficiency of lysine deposition is assumed to be 72% in InraPorc. The maximum efficiency of the other AA is calculated from the maximum efficiency of lysine utilisation and the ideal protein profile. The maximum efficiency for amino acid utilisation is only applied to AA used for PD and not to AA used for maintenance.
It can be concluded that the feed intake curve and the PD curve are the main determinants for the amino acid requirements in growing and finishing pigs and the required amino acid content in the diet.

2.2 Estimation amino acid requirements

The SID lysine requirement is predicted with InraPorc (Van Milgen et al., 2008). Because InraPorc is based on fixed ratios between SID lysine and other essential AA, that cannot be changed by the user of the model, it was decided to estimate the requirement of the other essential AA based on literature. In the literature, different models are used to describe the response of the pig to the increase in amino acid supply (Van Milgen and Dourmad, 2015). The linear-plateau (or broken line) and curvilinear-plateau models are most frequently used (Robbins et al., 2006). Asymptotic and quadratic models have also been used, but these models have the disadvantage that a maximum of the response criterion is never achieved (asymptotic model) or that the model predicts a decline in the response criterion for greater levels of the amino acid (Van Milgen and Dourmad, 2015). The linear-plateau model and the curvilinear-plateau model differ conceptually in that the marginal response below the amino acid requirement is constant for the linear-plateau model and a curvilinear function of the amino acid supply for the curvilinear-plateau model (Van Milgen and Dourmad, 2015). This conceptual difference has an important impact on the estimate of the amino acid requirement and estimates obtained with the curvilinear-plateau model are greater than those estimated by the linear-plateau model (Figure 2; Ajinomoto Eurolysine S.A.S., 2012; Van Milgen and Dourmad, 2015). Pomar et al. (2003) suggested that a linear-plateau model should be used for individual animals, while a curvilinear-plateau model is best suited for a population or group of animals.

Linear-plateau model



Curvilinear-plateau model

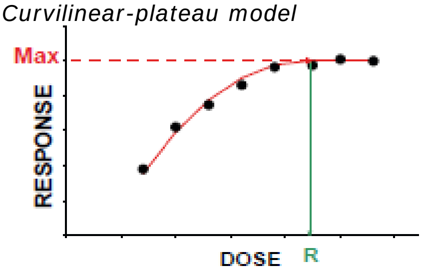


Figure 2 *Graphic representation of a response to a dose of AA; R represent the requirement of an amino acid; the requirement is lower by using a linear-plateau model than by using a curvilinear-plateau model (Ajinomoto Eurolysine S.A.S., 2012)*

The difference in requirements estimated by the two models illustrate that the actual requirement of an amino acid should be interpreted with caution and that is important to interpret reported amino acid requirement values in relation to the model with which they were estimated (Liu et al., 2015; Van Milgen and Dourmad, 2015). Moreover, it is important to know which response parameter is used (for instance daily gain or feed conversion ratio), because there can be a difference between the response parameters on an increase in amino acid supply (Liu et al., 2015).

Because a curvilinear-plateau model is best suited to predict the SID AA requirement for a population or group of animals (Pomar et al., 2003) and because the SID lysine requirement in InraPorc (Van Milgen et al., 2008) is predicted with a curvilinear-plateau model, we decided to use the curvilinear-plateau model to predict the requirements of the other AA.

3 Requirement of Lysine

The SID lysine requirement is predicted with InraPorc (Van Milgen et al., 2008). The InraPorc decision support software consists of a feed module and a growing-finishing pig module. The feed module is required to define the content and digestibility of dietary nutrients. In order to perform a simulation, a feeding strategy and an animal profile is required. A feeding strategy consists of a feed sequence plan and a feed rationing plan. The feed sequence plan indicates which feeds will be used during the simulation. The feed rationing plan indicates the quantity of feed that is provided and consumed by the animal. In the animal profile, the potential feed intake and performance of a pig is given.

3.1 Model input

Feeding strategy

To predict the SID lysine requirement for the current and future growing and finishing pigs with InraPorc (Van Milgen et al., 2008), the following feeding strategy is used:

- From 25 to 50 kg pigs are fed a starter diet (EW_{2015} = 1.10; NE_{2015}= 9.68 MJ/kg);
- From 50 to 80 kg pigs are fed a grower diet (EW_{2015} = 1.10; NE_{2015} = 9.68 MJ/kg);
- From 80 to 120 kg pigs are fed a finisher diet (EW_{2015} = 1.10; NE_{2015} = 9.68 MJ/kg).

All three diets are formulated with an oversupply of SID amino acids, except SID lysine, to be sure that the performance of the growing and finishing pigs will not be limited due to a shortage of one of these AA. The level of all other nutrients are adequate in all three diets. The calculations in InraPorc are based on the French NE system. The French NE system might differ from the Dutch NE system. However, because we do not know if there is a difference, how big this difference is and what the effect of a possible difference might be, we supposed that there is no influence of the French NE system compared to the Dutch NE system on the SID lysine requirement.
The growing and finishing pigs are fed ad libitum. The ad libitum feed intake is a function of body weight and can be predicted by a linear, power and exponential equation (Figure 3) (Van Milgen et al., 2008). We choose the exponential equation because this predicted curve best reflects the course of the feed intake in growing and finishing pigs in experiments (e.g. Van der Peet-Schwering et al., 2012).

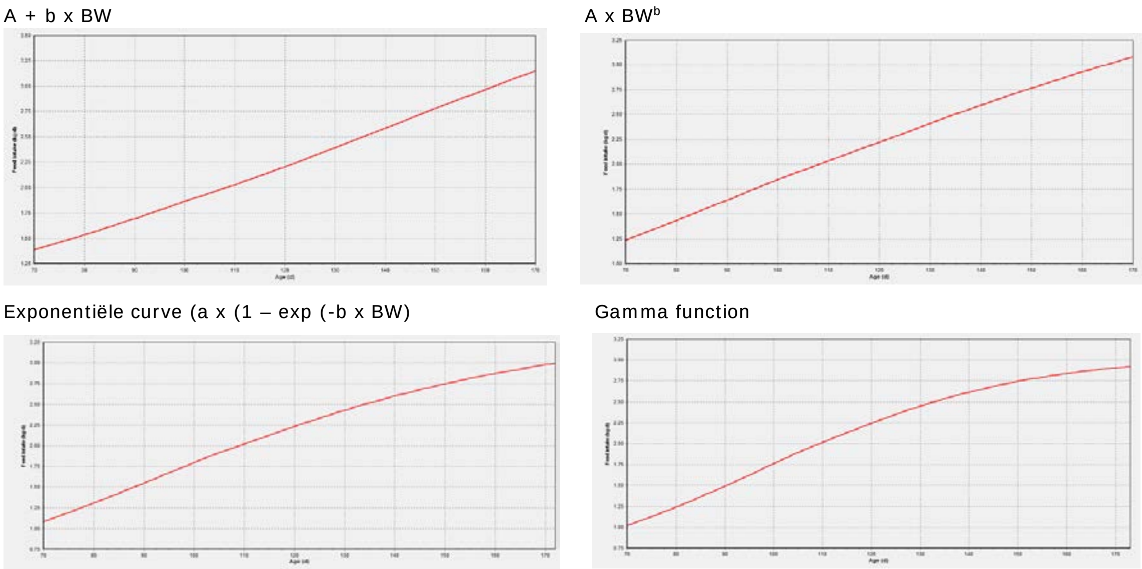


Figure 3 *Ad libitum feed intake curves predicted with InraPorc (Van Milgen et al., 2008)*

Animal profile
The growing and finishing pigs are characterized by: initial age (d), initial body weight (kg), final body weight (kg), feed intake at a body weight of 50 kg (kg/d), feed intake at a body weight of 100 kg (kg/d), mean PD (g/d), body weight at which the marginal PD becomes zero (BWPDmax) and precocity (protein deposition is defined by a Gompertz function; the shape parameter of the Gompertz function is called 'precocity').
We characterized a current and a future growing and finishing boar, gilt and barrow. For all characterized pigs we choose an initial BW of 25 kg, a final BW of 120 kg and BWPDmax of 70 kg. The performance of the current growing and finishing pigs is based on the performance of growing and finishing boars, gilts and barrows in the control group as published by Van der Peet-Schwering et al. (2012). These performance data are about 5% better than the mean performance of the growing and finishing pigs in the Netherlands as published in the Kengetallenspiegel 2016 (Agrovision, 2017). Because the pigs in the trial of Van der Peet-Schwering et al. (2012) were weighed every two weeks and the feed intake was measured every two weeks, we knew the feed intake at a BW of 50 and 100 kg and the mean PD over the growing period (related to the average daily gain) quite accurate. The value for the precocity was predicted with help of the calibration function in InraPorc.
For the future growing and finishing pigs, we supposed that their daily gain is 10% higher than the daily gain of the current growing and finishing pigs. A 10% higher daily gain can be realized by a 10% higher feed intake, a 10% improved feed conversion ratio or a combination of a higher feed intake and an improved feed conversion ratio. The SID lysine requirement for the future growing and finishing pigs is estimated in case that the 10% higher daily gain is realized by a 10% higher feed intake or by a 10% improved feed conversion ratio. We supposed that the daily gain of the future pigs is about 10% higher than the daily gain of the current pigs in all three phases (25-50 kg, 50-80 kg and 80-120 kg). The other model parameters were calibrated manually so that the predicted daily gain corresponds as close as possibly to the supposed daily gain of the future pigs. This resulted in an overall higher feed intake of 10% in the future pigs, but not in a 10% higher feed intake in all the phases (about 6, 9 and 11% higher in respectively phase 1, 2 and 3; see Table 3). The same applies to the improved feed conversion ratio. The overall feed conversion ratio is improved with about 10%, but the feed conversion is phase 1, 2 and 3 is improved with respectively 4, 9 and 13% (see Table 3).

In Table 2, the characterization of the current and future growing and finishing pigs is presented.

Table 2 *Characterization of the current and future[1] growing and finishing pigs*

	Current growing and Finishing pigs			Future growing and finishing pigs: 10% higher feed intake			Future growing and finishing pigs: 10% improved feed conversion ratio		
	Boar	Gilt	Barrow	Boar	Gilt	Barrow	Boar	Gilt	Barrow
Starting point:									
ADG[2] (g/d)	862	843	823	948	927	905	948	927	905
ADFI[2] (kg/d)	1.98	2.08	2.11	2.18	2.29	2.32	1.98	2.08	2.11
FCR[2]	2.30	2.47	2.57	2.30	2.47	2.57	2.09	2.24	2.33
Model input:									
Initial age (d)	70	70	70	70	70	70	70	70	70
BW[2] at start (kg)	25	25	25	25	25	25	25	25	25
BW at finish (kg)	120	120	120	120	120	120	120	120	120
FI 50 kg[2]	1.77	1.85	1.89	1.90	1.98	2.01	1.77	1.84	1.89
FI 100 kg[2]	2.40	2.52	2.52	2.67	2.79	2.79	2.40	2.44	2.47
PD[2] mean (g/d)	145	136	132	158	149	144	163	156	151
Precocity	0.01224	0.01218	0.01379	0.01400	0.01400	0.01550	0.01314	0.01308	0.01489
BWPDmax[2] (kg)	70	70	70	70	70	70	70	70	70

[1] The daily gain of the future growing and finishing pigs is 10% higher than the daily gain of the current growing and finishing pigs and is realized by a 10% higher feed intake or a 10% improved feed conversion ratio; [2] ADG = average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio; BW = body weight; FI 50 kg = feed intake at a BW of 50 kg; FI 100 kg = feed intake at a BW of 100 kg; PD = protein deposition; BWPDmax = BW at which the marginal PD becomes zero.

3.2 Prediction of SID lysine requirement

For the growing and finishing pigs characterized in Table 2, the SID lysine requirement is estimated with InraPorc (Van Milgen et al., 2008). For all three phases (25-50 kg, 50-80 kg and 80-120 kg), the SID lysine requirement (expressed as g/kg, g/MJ NE and as g/EW_{2015}) at the beginning of the phase is predicted. Moreover, the SID lysine requirement in g/d is calculated at 25 kg (day 1 of phase 1), at 50 kg (day 1 of phase 2) and at 80 kg (day 1 of phase 3). The results per phase of the simulations with InraPorc are presented in Table 3. The daily SID lysine required for maintenance and protein deposition and the daily excess of SID lysine during the growing-finishing period for the current and future growing and finishing boars is presented in Figures 4-6. The daily SID lysine required for maintenance and protein deposition and the daily excess of SID lysine during the growing-finishing period for the current and future growing and finishing gilts and barrows is presented in Appendix 1.

Table 3 *Performance and SID lysine requirement (g/kg, g/MJ NE, g/EW_{2015} and at day 1 of each phase) of current and future[1] growing and finishing pigs as predicted with InraPorc (Van Milgen et al., 2008)*

	Current growing and Finishing pigs			Future growing and finishing pigs: 10% higher feed intake			Future growing and finishing pigs: 10% improved feed conversion ratio		
	Boar	Gilt	Barrow	Boar	Gilt	Barrow	Boar	Gilt	Barrow
25-120 kg:									
ADG[2] (g/d)	869	841	826	957	929	906	956	929	905
ADFI[2] (kg/d)	1.99	2.08	2.11	2.19	2.29	2.32	1.99	2.09	2.11
FCR[2]	2.29	2.47	2.56	2.29	2.46	2.57	2.09	2.25	2.33
Mean PD[2] (g/d)	145	136	132	157	148	142	163	156	149
25-50 kg:									
ADG (g/d)	763	746	774	843	830	852	829	820	847
ADFI (kg/d)	1.45	1.51	1.56	1.53	1.60	1.63	1.45	1.52	1.56
FCR	1.90	2.03	2.01	1.82	1.93	1.92	1.75	1.85	1.85
Mean PD (g/d)	125	120	124	139	134	137	139	135	138
SID lysine (g/kg)[3]	9.60	9.14	9.14	10.10	9.60	9.60	10.51	9.60	9.78
SID lysine (g/MJ NE)	0.99	0.94	0.94	1.04	0.99	0.99	1.09	0.99	1.01
SID lysine (g/EW_{2015})[4]	8.73	8.31	8.31	9.14	8.73	8.73	9.55	8.73	8.89
SID lysine at 25 kg (d1 of phase 1) (g/d)	11.2	11.0	11.2	12.1	11.7	12.0	11.9	11.5	11.9
50-80 kg:									
ADG (g/d)	924	893	889	1018	991	980	1014	990	980
ADFI (kg/d)	2.02	2.11	2.14	2.19	2.29	2.32	2.02	2.08	2.13
FCR	2.18	2.37	2.41	2.15	2.31	2.36	1.99	2.10	2.17
Mean PD (g/d)	154	145	143	168	160	157	173	166	163
SID lysine (g/kg)[3]	8.37	7.82	7.82	8.60	7.98	7.82	9.38	8.76	8.60
SID lysine (g/MJ NE)	0.86	0.81	0.81	0.89	0.82	0.81	0.97	0.90	0.89
SID lysine (g/ EW_{2015})	7.61	7.11	7.11	7.82	7.25	7.11	8.53	7.96	7.82
SID lysine at 50 kg (d1 of phase 2) (g/d)	15.2	14.6	14.9	16.3	16.0	15.8	16.7	16.3	16.3
80-120 kg:									
ADG (g/d)	911	874	816	996	957	890	1012	960	893
ADFI (kg/d)	2.39	2.50	2.50	2.65	2.79	2.79	2.39	2.45	2.47
FCR	2.62	2.87	3.07	2.68	2.91	3.13	2.37	2.56	2.76
Mean PD (g/d)	153	141	128	163	150	136	175	163	147
SID lysine (g/kg)[3]	7.49	6.74	6.37	7.49	6.74	6.37	8.39	7.86	7.49
SID lysine (g/MJ NE)	0.77	0.70	0.66	0.77	0.70	0.66	0.87	0.81	0.77
SID lysine (g/ EW_{2015})	6.81	6.13	5.79	6.81	6.13	5.79	7.63	7.15	6.81
SID lysine at 80 kg (d1 of phase 3) (g/d)	16.5	15.8	15.0	18.4	17.3	16.4	18.7	17.9	17.4

[1] The daily gain of the future growing and finishing pigs is 10% higher than the daily gain of the current growing and finishing pigs and is realized by a 10% higher feed intake or a 10% improved feed conversion ratio; [2] ADG = average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio; PD = protein deposition; [3] NE in the diet is 9.68 MJ NE; [4] 1 EW_{2015} = 8.8 MJ NE.

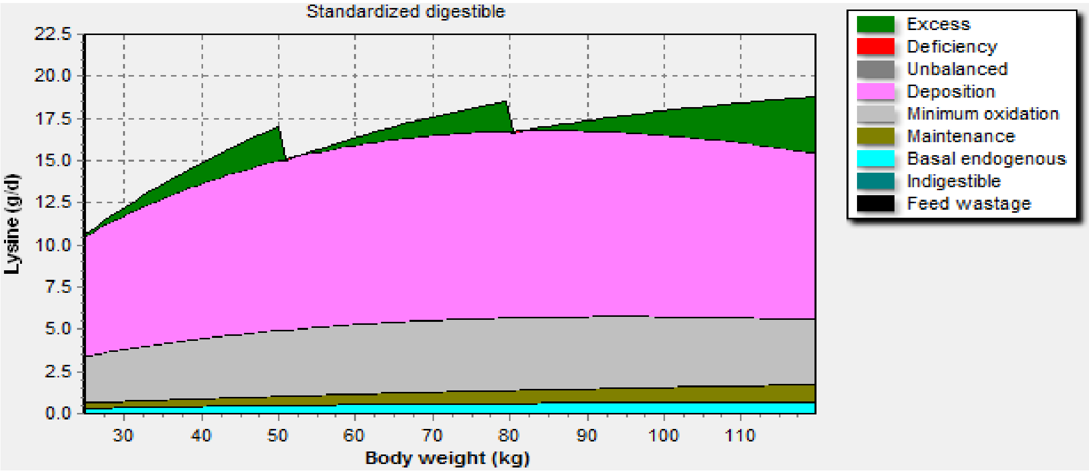


Figure 4 *Daily SID lysine required for maintenance (brown) and protein deposition (pink) and daily excess (green) of SID lysine for the current growing and finishing boar (current CVB +5% lysine in starter diet and +7% lysine in grower diet)*

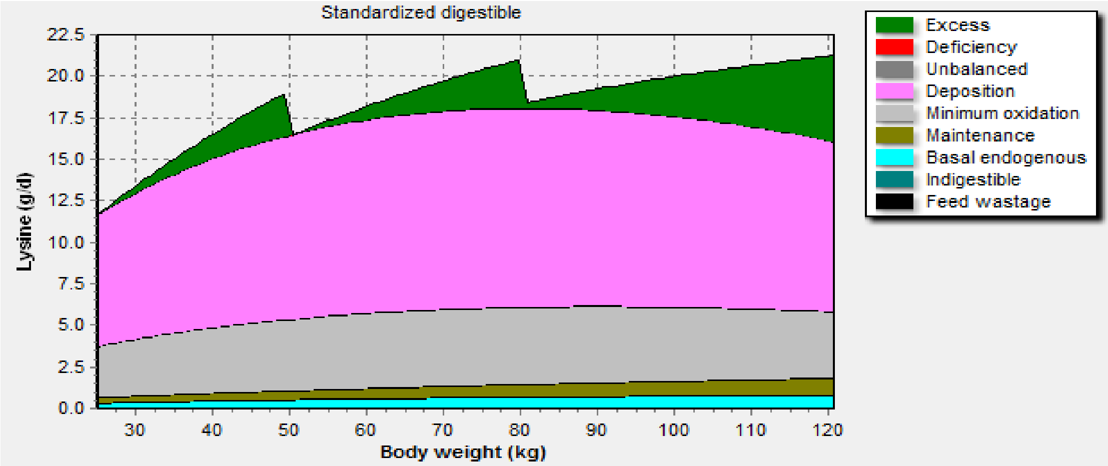


Figure 5 *Daily SID lysine required for maintenance (brown) and protein deposition (pink) and daily excess (green) of SID lysine for the future (10% higher daily gain and feed intake) growing and finishing boar (current CVB +10% lysine in starter diet and +10% lysine in grower diet)*

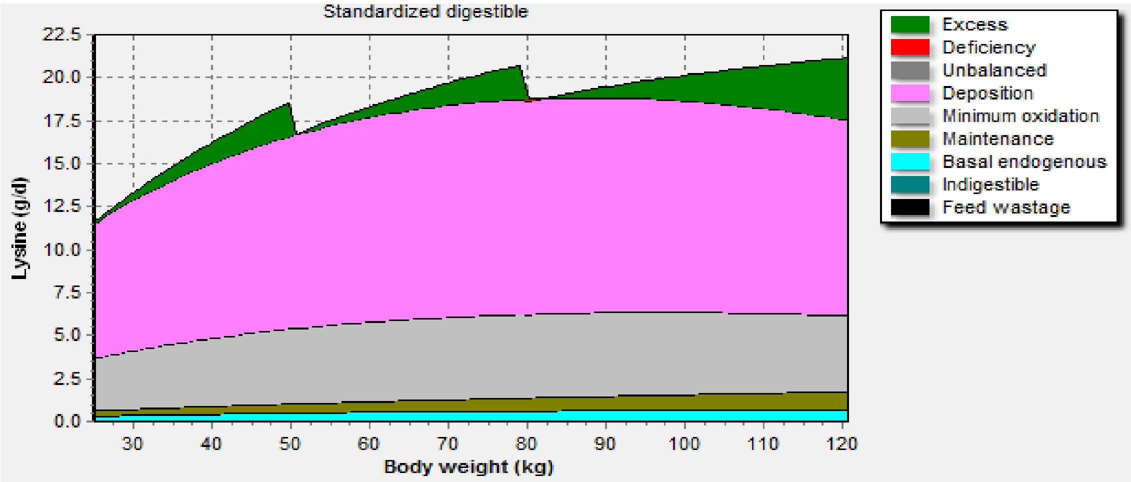


Figure 6 *Daily SID lysine required for maintenance (brown) and protein deposition (pink) and daily excess (green) of SID lysine for the future (10% higher daily gain and improved feed conversion ratio) growing and finishing boar (current CVB +15% lysine in starter diet, +20% lysine in grower diet and +12% in finisher diet)*

The results in Table 3 show that the SID lysine requirement per kg of feed of the future growing and finishing pigs with an improved feed conversion ratio is higher than the SID lysine requirement of the current growing and finishing pigs. The daily SID lysine requirement (expressed in g/d) is higher in future pigs than in current pigs because of the higher daily gain and mean PD. The daily feed intake of the current pigs and the future pigs with an improved feed conversion ratio, however, is similar resulting in a higher SID lysine requirement per kg of feed of the future pigs with an improved feed conversion ratio.

In the future pigs with a higher feed intake, the SID lysine requirement per kg of feed is higher than in the current pigs only during the starter phase and grower phase but not during the finisher phase. As mentioned before, we supposed that the daily gain of the future pigs is about 10% higher than the daily gain of the current pigs in all three phases (25-50 kg, 50-80 kg and 80-120 kg). In the future pigs with a higher feed intake, the overall feed intake indeed was 10% higher than in the current pigs. In the starter and grower phase, however, the feed intake was respectively 6 and 9% higher in the future pigs compared with the current pigs, resulting in an improved feed conversion ratio and a higher SID lysine requirement per kg of feed of the future pigs in these phases.

3.3 Discussion predicted SID lysine requirement

SID lysine requirement predicted at the beginning of each phase

For all three phases (25-50 kg, 50-80 kg and 80-120 kg), the SID lysine requirement (expressed as g/kg and as g/EW_{2015}) at the beginning of the phase is predicted. As the SID lysine requirement per kg of feed declines with age, but the supply remains the same within a phase, an increasing oversupply of SID lysine will be given during each phase (see Figures 4-6). Therefore, the effect of 5 or 10% less SID lysine supply during the whole growing and finishing period on the performance of the pigs is calculated with InraPorc. This is calculated for the current and future growing and finishing boars. The effect of 5 or 10% less SID supply on the overall performance is presented in Table 4. The effect of 5 or 10% less SID supply on the development of daily gain is presented in Figures 7-9.

Table 4 *Effect of 100%, 95% and 90% supply of SID lysine requirement predicted in Table 3 on the performance of the current and future[1] growing and finishing boars as predicted with InraPorc (Van Milgen et al., 2008)*

	Current growing and Finishing boar			Future growing and finishing boar 10% higher feed intake			Future growing and finishing boar 10% improved feed conversion ratio		
SID lysine supply	100%	95%	90%	100%	95%	90%	100%	95%	90%
25-120 kg:									
ADG[2] (g/d)	869	861	837	957	951	932	956	948	921
ADFI[2] (kg/d)	1.99	1.98	1.97	2.19	2.18	2.18	1.99	1.99	1.99
FCR[2]	2.29	2.30	2.35	2.29	2.29	2.33	2.09	2.10	2.16
Mean PD[2] (g/d)	145	143	138	157	156	152	163	161	156

[1] The daily gain of the future growing and finishing pigs is 10% higher than the daily gain of the current growing and finishing pigs and is realized by a 10% higher feed intake or a 10% improved feed conversion ratio; [2] ADG = average daily gain; ADFI = average daily feed intake; FCR = feed conversion ratio; PD = protein deposition

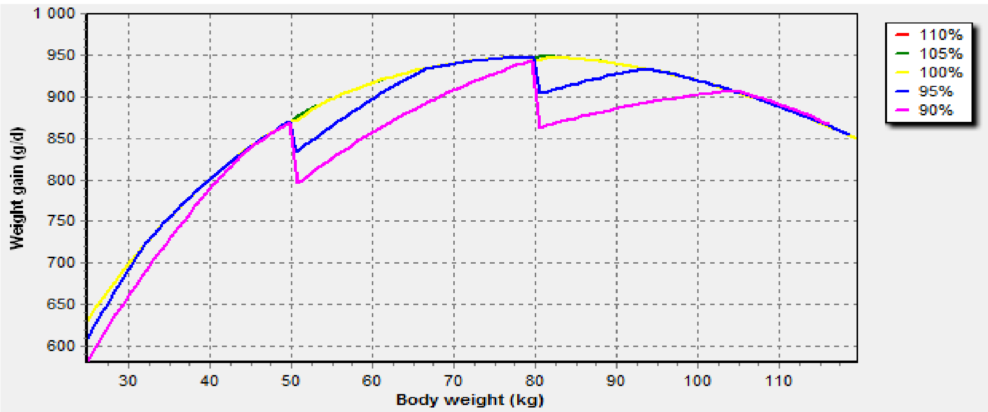


Figure 7 *Effect of 105% (green line), 100% (yellow line), 95% (blue line) and 90% (pink line) supply of SID lysine requirement predicted in Table 3 on daily gain of the current growing and finishing boar*

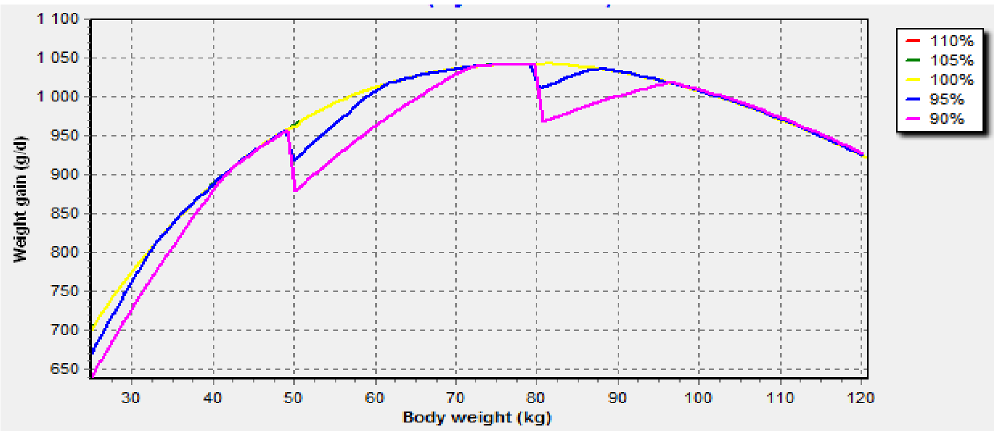


Figure 8 *Effect of 100% (yellow line), 95% (blue line) and 90% (pink line) supply of SID lysine requirement predicted in Table 3 on daily gain of the future (10% higher daily gain and feed intake) growing and finishing boar*

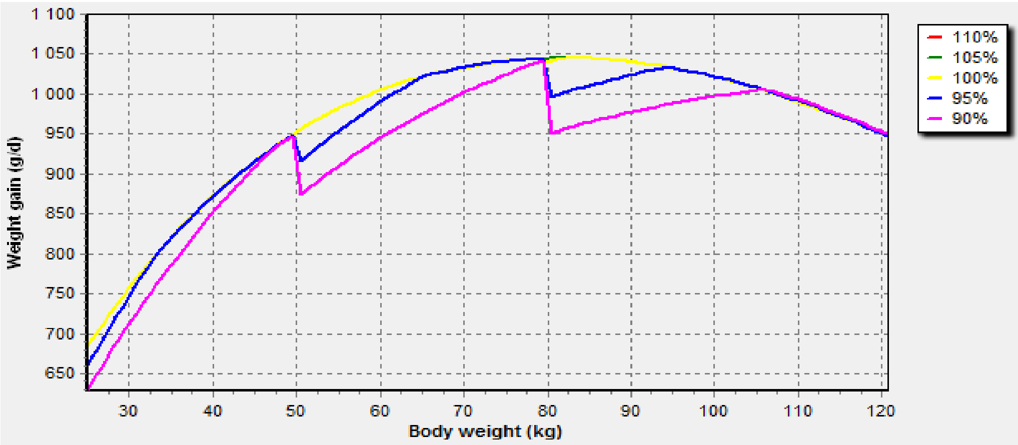


Figure 9 *Effect of 100% (yellow line), 95% (blue line) and 90% (pink line) supply of SID lysine requirement predicted in Table 3 on daily gain of the future (10% higher daily gain and improved feed conversion ratio) growing and finishing boar*

The effect of 5% less SID lysine in the diets on the performance of the current and future boars is relatively small. A reduction of 10% SID lysine in the diets, however, will reduce average daily gain with about 3 to 4% and will increase the feed conversion ratio with about 2 to 3% in the current and future growing and finishing boars. These results also apply to current and future barrows and gilts.

SID lysine requirement of one pig vs a population of pigs

It is important to realise that InraPorc predicts the requirement for an individual pig (the average pig) (Van Milgen et al., 2008). This requirement should not be interpreted as the average requirement for a population of pigs because of the variation in performance between individual pigs in a population. If a population is fed according to the average pig, only those pigs with a requirement lower or equal than the average pig will be able to express their growth potential, whereas the requirement of the pigs with a greater potential performance (about half of the herd) will not be met resulting in a lower performance than their potential performance (Van Milgen et al., 2008). Consequently, the mean performance of the herd will be lower than expected. Brossard et al. (2009) used a stochastic approach of InraPorc to study the variation in response between animals. They calculated the percentage of pigs for which the SID lysine requirement was met at the beginning and at the end of each feeding phase. The used SID lysine levels supplied 70%, 80%, 90%, 100%, 110%, 120% or 130% of the requirement of the average pig at the beginning of a feeding phase (see Figure 10).

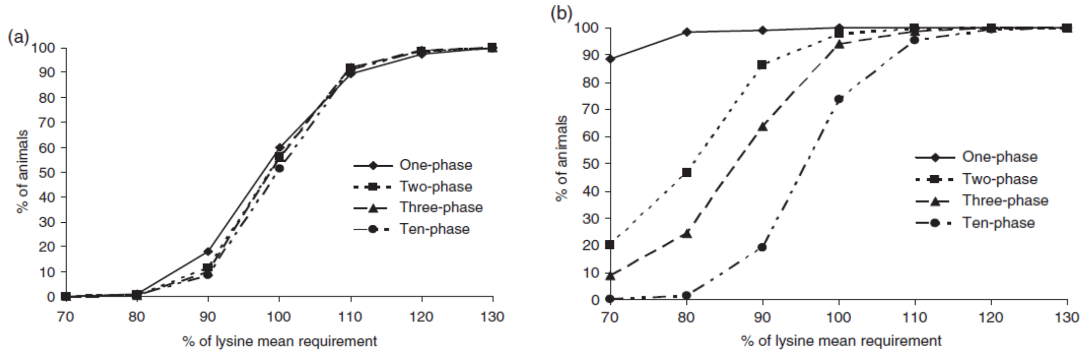


Figure 10 *Effect of lysine supply (as % of the lysine requirement of the average pig) and feed sequence plan (one, two, three or ten phase feeding) on the percentage of pigs for which the lysine requirement was met at the beginning (a) or at the end of the phase (b) (Brossard et al., 2009)*

At the beginning of a phase, the percentage of pigs for which the SID lysine requirement was met at 100% SID lysine supply was 56%. This percentage increased with time within a phase. At a 110% SID lysine supply, the percentage of pigs for which the SID lysine requirement was met, was almost 90%. At the end of a feeding phase, the percentage of pigs for which the SID lysine requirement was met at 100% SID lysine was about 90% for pigs fed by three-phase feeding. At a 110% SID lysine supply, this percentage was almost 100%. Brossard et al. (2009) concluded that the SID lysine requirement of a population of pigs is about 10% higher than the SID lysine requirement of the average pig (see Figure 10). At this level of SID lysine supply, the simulated performance of most of the pigs in the population was close to maximum. Above this level of SID lysine supply, performance of the pigs did not further increase. At lower levels of SID lysine supply, the simulated performance decreased because not all pigs in the population were fed to their SID lysine requirement.

4 Requirement of other essential AA

In this section an overview of literature data of the last 10 years on the requirements of other essential AA than lysine is presented. As a starting point, the current recommendations for SID amino acids in different countries are presented. The levels of other essential AA are expressed as a ratio to SID lysine based on the concept of “ideal protein”.

4.1 Current recommendations for amino acids

In Table 5, the current recommendations for SID essential AA in starter, grower and finisher pig diets in different countries are presented. The recommendations are expressed in % of SID lysine.

Table 5 *Current recommendations for SID essential AA in starter, grower and finisher pig diets (expressed in % of SID lysine)*

	Inra, 2008	NRC, 2012	Seges Svineproduktion, 2016	Ajinomoto Eurolysine, 2016	CVB, 1996 (% of AID Lysine)	CVB, 1996 (% of SID Lysine)
Methionine+Cystine	60	57-59[1]	57-61[1]	60	59-61[1]	60-62[1]
Threonine	65	63-67[1]	63-67[1]	67-68[1]	57-60[1]	61-65[1,2]
Tryptophan	18	18	20	20	19	20
Isoleucine	55	51-52[1]	53	53	-	-
Valine	70	66-68[1]	67	65	-	-
Leucine	100	101-102[1]	100	100	-	-
Histidine	32	34	32	32	-	-
Phenylalanine+Tyrosine	95	95-97[1]	100	95	-	-

[1] The recommended ratio increases with increasing weight of the growing and finishing pigs

[2] Compared with other AA, threonine digestibility increases the most when moving from apparent to standardized ilea digestibility because of the relatively high level of threonine in basal endogenous protein.

As can be seen in Table 5, there are small differences in the recommendations between the different countries. These differences in recommendations are probably partly due to different models and/or different response parameters that are used to predict the AA requirements. Besides, the Danish standards are based on an economically optimum standard, as a standard for maximum productivity would increase feed costs more than can be covered by productivity improvements (Tybirk et al., 2016). In the Netherlands, there are only public recommendations for methionine+cystine, threonine and tryptophan and not for the other essential AA. Because the substantiation of the recommendations in other countries is not always clear, we decided to perform our own literature review to determine the recommendations for other essential AA than lysine.

4.2 Total Sulphuric AA (TSAA)

Recently, Ma et al. (2016) conducted an experiment to determine the optimum TSAA to lysine ratio for late finishing gilts (96 to 120 kg) fed low CP diets supplemented with crystalline AA ad libitum. The optimum SID TSAA to lysine ratios to maximize average daily gain as well as to minimize feed conversion ratio were 57% and 58% using a linear-plateau model and 64% and 62% using a quadratic model (Figure 11). Because a quadratic model often overestimates the nutritional requirement (Baker, 1986), Ma et al. (2016) concluded that in their study the appropriate SID TSAA to lysine ratio was obtained by the linear-plateau model. Moreover, they decided that minimizing FCR is economically more important than maximizing average daily gain. Therefore, in 96 to 120 kg gilts fed low CP diets, the SID TSAA to lysine ratio for lowest FCR was estimated as 58% (Ma et al., 2016).
As mentioned in section 2.2, estimates obtained with the linear-plateau model are lower than those estimated with the curvilinear-plateau model (Ajinomoto Eurolysine S.A.S., 2012; Van Milgen and

Dourmad, 2015). Besides Pomar et al. (2003) suggest that a linear-plateau model should be used for individual animals, while a curvilinear-plateau model is best suited for a population or group of animals. Therefore, the recommended SID TSAA to lysine ratio of 58% (Ma et al., 2016) might be too low for a population of pigs.

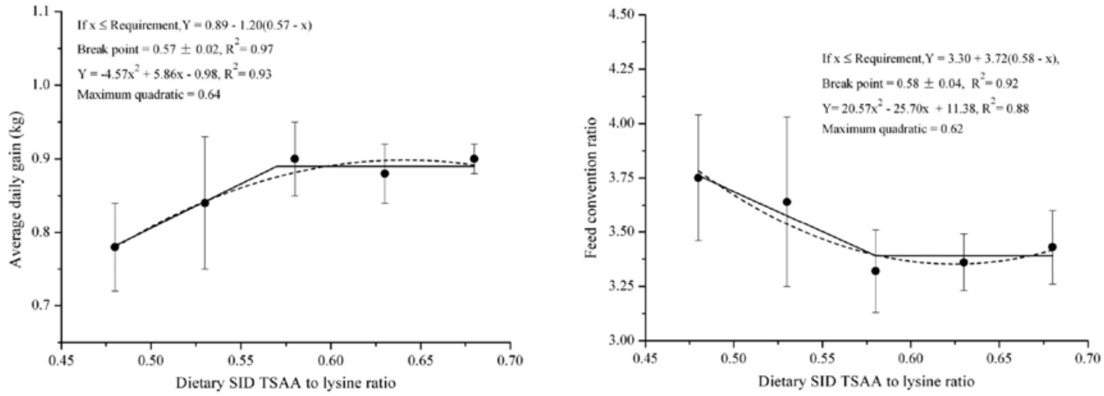


Figure 11 *Fitted linear-plateau model (—) and quadratic model (- -) of average daily gain and feed conversion ratio plotted against SID TSAA to lysine ratios in 96 to 120 kg gilts (Ma et al., 2016)*

Zhang et al. (2015) conducted an experiment to determine the optimum SAA to lysine ratio required to maximize the performance of 25 to 50 kg pigs fed low CP diets supplemented with crystalline AA ad libitum. The optimum SID SAA to lysine ratios for maximum average daily gain and minimum feed conversion ratio were 62.2 and 61.5% using a linear plateau model and 63.8 and 62.5% using a curvilinear-plateau model. Based on an average of these estimates, they conclude that the optimal proportion of SID SAA to lysine for pigs fed low CP diets supplemented with crystalline AA is 62.3% for 25–50 kg pigs.
Yi et al. (2005) estimated the optimum SID SAA to lysine ratio to be 61.7% for average daily gain and 61.1% for feed conversion ratio in 28–49 kg ad libitum fed mixed-sex pigs using a linear-plateau model. Similarly, Gaines et al. (2004) estimated the optimum proportion of SID SAA to lysine to be 59.7% and 61.1% for average daily gain and feed conversion ratio for 29–45 kg growing pigs. In a literature review, Peak (2005) reported the SID SAA to lysine ratio to be 60.0–62.0% for modern genotypes of nursery and growing pigs. In this review, it is not described which model is used.

Regarding the optimal ratio of methionine to SAA, Gillis et al. (2007) suggested an optimal ratio of 55.0% for 40-80 kg growing gilts. They investigated this ratio in relation to protein deposition using the nitrogen (N) balance technique. The data from their study showed that the minimum dietary available methionine to SAA ratio at which whole-body PD was maximized in gilts between 40 and 80 kg BW was 55% on a weight basis. They used a number of models to fit the data. The greatest proportion of the variation (R^2 = 0.99) was explained with an asymptotic model.
Qiao et al. (2008) investigated the optimal ratio of methionine to SAA in a N-balance trial with 20-30 kg growing barrows. The quadratic regression model was used to determine the optimum ratio of methionine to SAA. The optimal ratio of methionine to SAA was estimated to be 54.15% for N-retention. The CVB (2012) advises a minimum ratio of methionine to SAA of 55%.

Based on the available literature, we recommend a SID SAA to lysine ratio from 60 to 62% for growing and finishing pigs and a ratio of methionine to SAA of 55%. This recommended SID SAA to lysine ratio is in agreement with the recommendations of Ajinomoto Eurolysine S.A.S. (2016) and INRA (2008) but slightly higher than the recommendations of Seges Svineproduktion (Tybirk et al., 2016) and NRC (2012).

4.3 Threonine

Based on a literature review, Ajinomoto Eurolysine S.A.S. (2008) recommend a SID threonine to lysine ratio of 67 and 68%, respectively, for growing and finishing pigs using a curvilinear-plateau model (Figure 12).

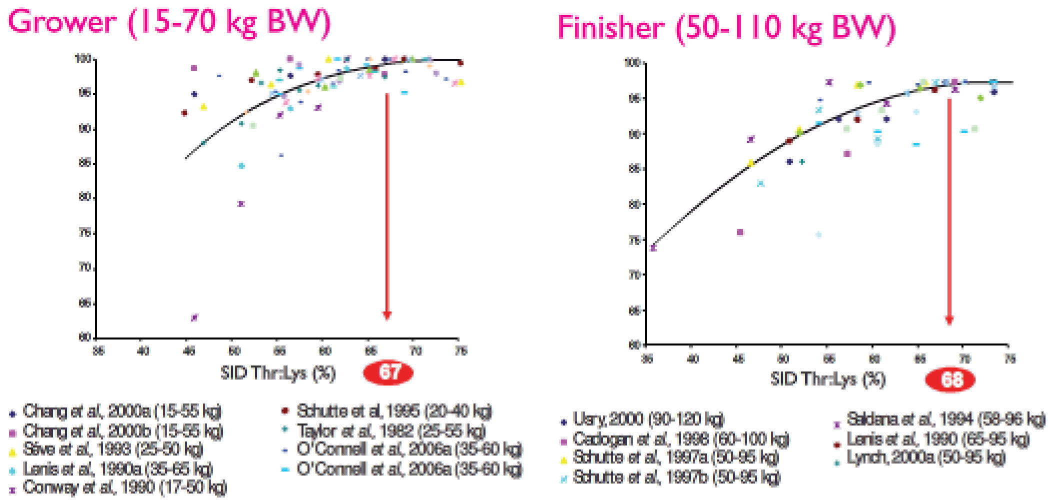


Figure 12 *Effect of SID threonine to lysine ratio on average daily gain (% of the best performance) in growing and finishing pigs (Ajinomoto Eurolysine S.A.S., 2008)*

More recently, in a study of Zhang et al. (2013), in which 22-50 kg pigs were fed low CP diets supplemented with crystalline AA ad libitum, the optimum SID threonine to lysine ratio was estimated as 68% and 67% for average daily gain and feed conversion ratio, respectively, by using a linear-plateau analysis. A curvilinear-plateau analysis estimated the optimum SID threonine to lysine ratio as 73% and 70% for average daily gain and feed conversion ratio, respectively. Taking an average of these values, Zhang et al. (2013) conclude that the optimum SID threonine to lysine ratio for 22–50 kg pigs fed low CP protein diets supplemented with crystalline AA is 70% to maximize average daily gain and 68% to optimize feed conversion ratio. They concluded that although the results of their study are within the range of previously reported values for the optimum SID threonine to lysine ratio for growing pigs, the results obtained tend to be on the high side of the range. Because in their study the crude protein level in the diet was reduced by 40 g/kg, Zhang et al. (2013) speculated that the optimal SID threonine to lysine ratio may be dependent on the crude protein content of the diet.
In a study of Xie et al. (2013), in which finishing pigs (72 kg BW at the start of the experiment) were fed low crude protein diets ad libitum, the optimum SID threonine to lysine ratios for maximal weight gain and minimal feed conversion ratio were 67% and 71%, respectively, using a linear-plateau model and 68% and 78%, respectively using a quadratic model (Figure 13). The ratio of 78% may be overestimated, because, as can be seen in Figure 13, feed conversion ratio is lowest at a SID threonine to lysine ratio of 72%. Like Zhang et al. (2013), Xie et al (2013) concluded that although the results of their study are within the range of previously reported values for the optimum SID threonine to lysine ratio for growing pigs, the results obtained tend to be on the high side of the range.

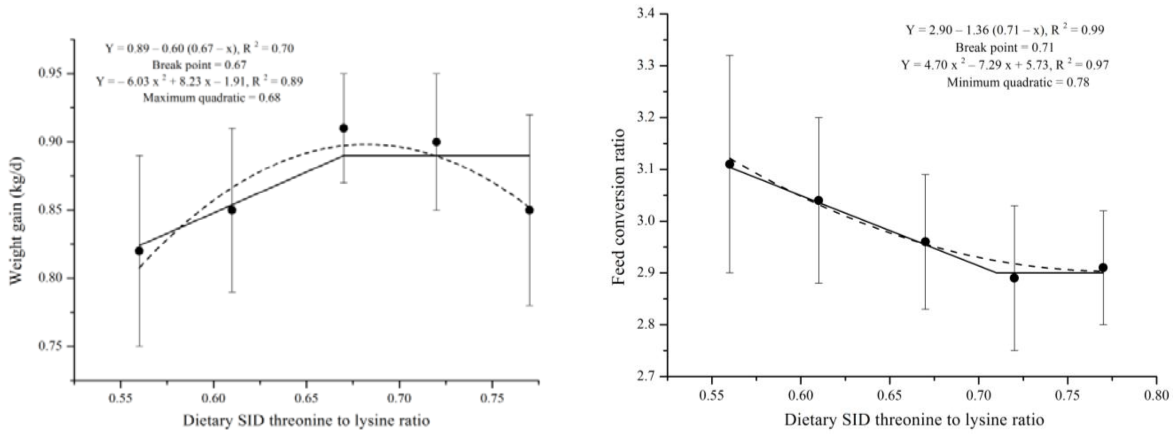


Figure 13 *Fitted linear-plateau analysis (—) and quadratic model (- -) of average daily gain and feed conversion ratio plotted against SID threonine to lysine ratios in barrows weighing 72.5 kg at the start of the trial (Xi et al., 2013)*

In a study of Ma et al. (2015a), in which 90-118 kg gilts were fed low crude protein diets ad libitum, the optimum SID threonine to lysine ratios to maximize average daily gain and to minimize feed conversion ratio were 61% and 63%, respectively, using a linear-plateau model and 70% and 74%, respectively, using a quadratic model (Figure 14).

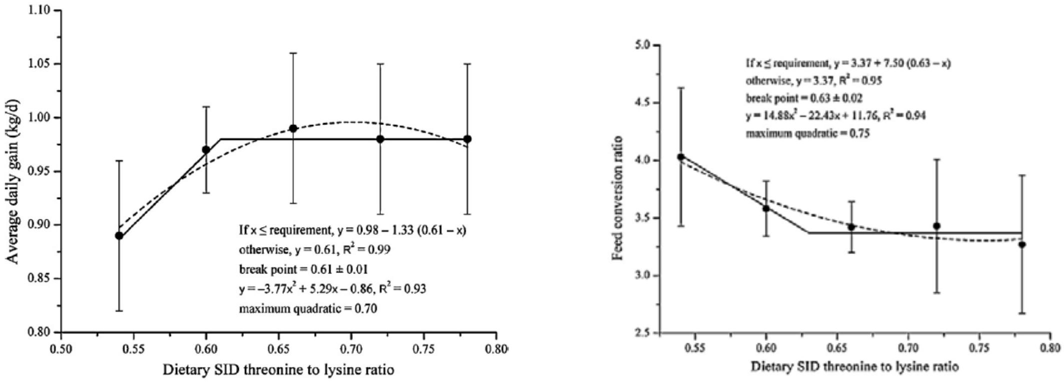


Figure 14 *Fitted linear-plateau analysis (──) and quadratic model (- -) of average daily gain and feed conversion ratio plotted against SID threonine to lysine ratios in 90 to 118 kg gilts (Ma et al., 2015a)*

In the reviewed literature, the optimal SID threonine to lysine ratio varies between trials partly due to the used model and the used parameter (daily gain or feed conversion ratio) but also due to the different weight ranges of the pigs. The ideal SID threonine to lysine ratio tends to increase with increasing body weight due to the increased proportion of threonine needed for maintenance for finishing pigs (Hahn and Baker, 1995).

In conclusion, it seems that the CVB recommendation (CVB, 1996) on the SID threonine to lysine ratio from 61 to 65% might be too low for the current and future growing and finishing pigs. Based on recent literature, we recommend a minimum SID threonine to lysine ratio from 66 to 68% for growing and finishing pigs. This recommendation is in agreement with the recommendations of Ajinomoto Eurolysine S.A.S. (2016) but especially during the growing phase slightly higher than the recommendations of Seges Svineproduktion (Tybirk et al., 2016) and NRC (2012).

4.4 Tryptophan

Zhang et al. (2012) investigated the SID tryptophan to lysine ratio in 25-50 kg pigs, fed low crude protein diets supplemented with crystalline AA ad libitum. The SID tryptophan to lysine ratios to optimize average daily gain and feed conversion ratio were 19.7 and 20.0% by using a linear-plateau model, and 22.6 and 23.2% by using a curvilinear-plateau model, respectively. Taking an average of these values, the authors concluded that the optimum SID tryptophan to lysine ratio is at least 22%. This value is higher than the current recommendations (see Table 4).
Ma et al. (2015b) investigated the SID tryptophan to lysine ratio in 89-121 kg gilts, fed low crude protein diets supplemented with crystalline AA ad libitum. The SID tryptophan to lysine ratios to optimize average daily gain and feed conversion ratio were 16% and 17% by using a linear-plateau model, and 20% and 20% by using a quadratic model, respectively (Figure 15). They concluded that the appropriate SID tryptophan to lysine ratio was estimated as 17% for 89- to 121-kg gilts fed low crude protein diets using feed conversion ratio as the response criteria.

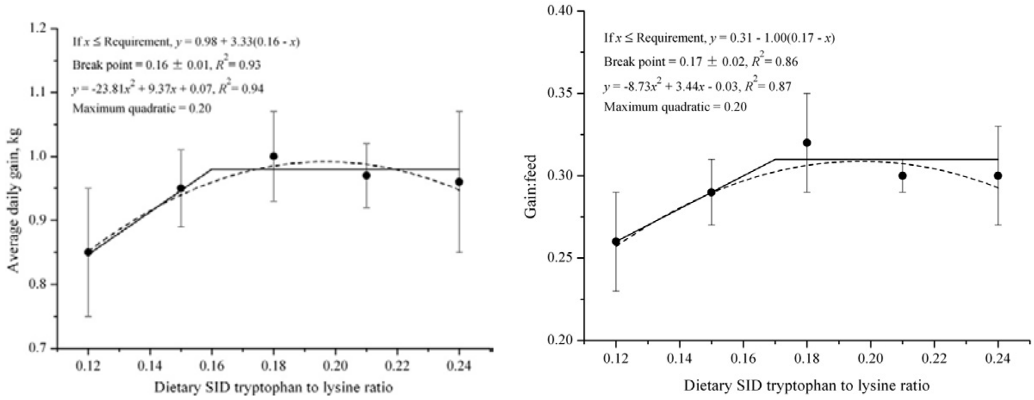


Figure 15 *Fitted linear-plateau analysis (——) and quadratic model (- -) of average daily gain and feed conversion ratio plotted against SID tryptophan to lysine ratios in 89 to 121 kg gilts (Ma et al., 2015b)*

In a study of Xie et al. (2014), conducted in 67–96 kg barrows fed low protein diets three times a day, the SID tryptophan to lysine ratios to optimize average daily gain and feed conversion ratio were 0.203 and 0.197 by using a linear-breakpoint model, and 0.251 and 0.224 by using a quadratic model, respectively. They concluded that the SID tryptophan to lysine ratio should be at least 0.203 for barrows fed a low protein corn, wheat bran, and soybean meal based diet.
Millet al al. (2015) fed growing pigs from 20-44 kg a low crude protein low tryptophan diet (138 g/kg and 16.5% SID tryptophan to lysine ratio) which was supplemented with increasing levels of tryptophan (dose-response) to yield different SID tryptophan to lysine ratios (16.5, 18.0, 19.5, 21.0 and 22.5%). With increasing tryptophan levels, pigs showed a linear increase in daily gain ($P < 0.001$) and a linear decrease in feed conversion ratio ($P = 0.003$). Although it was not possible to determine a break point with broken line models, the results suggest a SID tryptophan to lysine ratio greater than 19.5% (Millet et al., 2015).
Simongiovanni et al. (2013) performed a meta-analysis to estimate the SID tryptophan to lysine requirement ratio that maximises average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F) of pigs between 25 and 120kg body weight. They used the curvilinear-plateau model to estimate the animal response to increasing SID tryptophan to lysine ratios. The estimated SID tryptophan to lysine requirements were 20.9, 19.9 and 21.0%, for ADG, ADFI and G:F, respectively, with an average value of 20.6%. The response between 17 and 21% SID tryptophan to lysine levels was estimated to be +6.7 and +3.6%, for ADG and G:F, respectively.

Based on the reviewed literature, we recommend a minimum SID tryptophan to lysine ratio of 20% to optimize average daily gain and feed conversion ratio in growing and finishing pigs. This recommendation is in agreement with the recommendations of Ajinomoto Eurolysine S.A.S. (2016) and Seges Svineproduktion (Tybirk et al., 2016) but higher than the recommendations of INRA (2008) and NRC (2012).

4.5 Isoleucine

Van Milgen et al. (2012) carried out a meta-analysis of the available literature information to determine the isoleucine requirement in growing pigs. They concluded that the isoleucine requirement is influenced by the presence of blood products in the diet. The use of blood products in the diet was the main factor determining whether a response to the isoleucine concentration was observed or not. Blood meal and blood cells are protein sources with a very low isoleucine concentration, but with high or very high concentrations of leucine, valine, phenylalanine and histidine. Some of these AA, in particular leucine, compete with isoleucine for catabolic pathways or transport across the blood–brain barrier (Van Milgen et al., 2012). Excess leucine in the diet increases branch chain keto acid dehydrogenase levels which lead to catabolism of all branch chain AA. As a result, a large supply of leucine may increase the requirement for isoleucine and a greater isoleucine supply is required to maintain performance (Gloaguen et al., 2013). So, using blood products in diets for growing and finishing pigs appears to increase the requirement for SID isoleucine. Van Milgen et al. (2012) recommend a SID isoleucine to lysine ratio of 55% when blood products are used in the diet. In diets without blood products, the isoleucine requirement is lower than in diets with blood products. On the basis of the meta-analysis, Van Milgen et al. (2012) recommend a SID isoleucine to lysine ratio of at

least 50% in diets without blood products. A lower ratio is not advised, because a deficient isoleucine supply has a major impact on performance. A 10% reduction in the isoleucine concentration (below the requirement) resulted in a 15% reduction in feed intake and a 21% reduction in daily gain (Van Milgen et al., 2012).
Waguespack et al. (2012) investigated the SID isoleucine to lysine ratio in 20-45 kg pigs, fed low crude protein diets supplemented with crystalline AA ad libitum. They used corn-soybean meal diets without blood products. They concluded that the isoleucine requirement is 0.43% SID isoleucine. This means a SID isoleucine to lysine ratio of 52% in 20-45 kg growing pigs.
Htoo et al. (2014) studied the SID isoleucine to lysine ratio in 24-39 kg pigs fed diets containing moderate but non-excess levels of leucine (SID leucine to lysine ratio <130%) ad libitum.
The dietary SID isoleucine to lysine ratio to maximize ADG of 24- to 39-kg pigs was estimated to be 54% based on both curvilinear plateau and exponential regression, respectively. The gain to feed ratio was maximized at a SID isoleucine to lysine ratio of 50% and 53% by the curvilinear plateau and exponential regression, respectively. They concluded that the optimum SID isoleucine to lysine ratio was approximately 54% for 24-39 kg pigs fed diets containing non-excess levels of leucine.

Based on the available literature, we recommend a SID isoleucine to lysine ratio of 53% to optimize average daily gain and feed conversion ratio in growing and finishing pigs. This recommendation is in agreement with the recommendations of Ajinomoto Eurolysine S.A.S. (2016) and Seges Svineproduktion (Tybirk et al., 2016) but slightly higher than the recommendations of NRC (2012).

4.6 Valine

Research on the requirements for SID valine in growing and finishing pigs is scarce. Liu et al. (2015) conducted four experiments to determine SID valine to lysine ratio required for 26 to 46 kg (Exp. 1), 49 to 70 kg (Exp. 2), 71 to 92 kg (Exp. 3), and 94 to 119 kg (Exp. 4) pigs fed low CP diets supplemented with crystalline AA ad libitum. The dietary SID valine to lysine ratios required to maximize average daily gain for 26 to 46 kg, 49 to 70 kg, 71 to 92 kg, and 94 to 119 kg pigs were estimated to be 62%, 66%, 67%, and 68%, respectively, using a linear plateau model and 71%, 72%, 73%, and 72%, respectively, using a quadratic model (Figure 16).

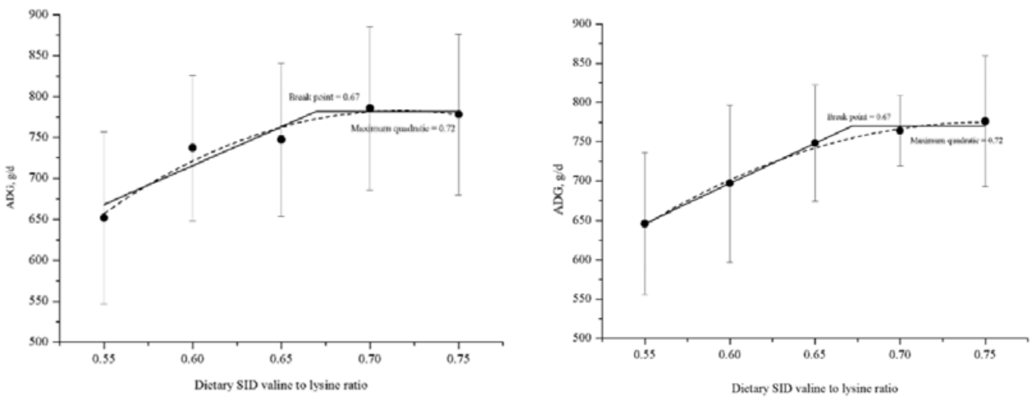
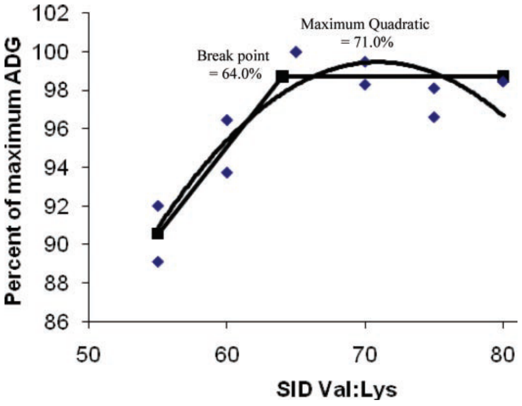


Figure 16 *Fitted linear plateau analysis (——) and quadratic model (- -) of average daily gain plotted against SID valine to lysine ratios in 49 to 70 kg and 71 to 92 kg growing and finishing pigs (Liu et al., 2015)*

Waguespack et al. (2012) investigated the SID valine to lysine ratio in 20-45 kg pigs, fed low crude protein diets supplemented with crystalline AA ad libitum. The SID valine to lysine ratios to maximize daily gain and to minimize feed conversion ratio were 70% and 67%, respectively, using a linear-plateau model.
Gaines et al. (2011) investigated the SID valine to lysine ration in 12 to 32 kg pigs ad lib fed pigs. The optimum SID valine to lysine ratios for maximum average daily gain and minimum feed conversion ratio were 64% and 65.1%, respectively, using a linear plateau model and 71% and 71.7%, respectively, using a quadratic model (see Figure 17).



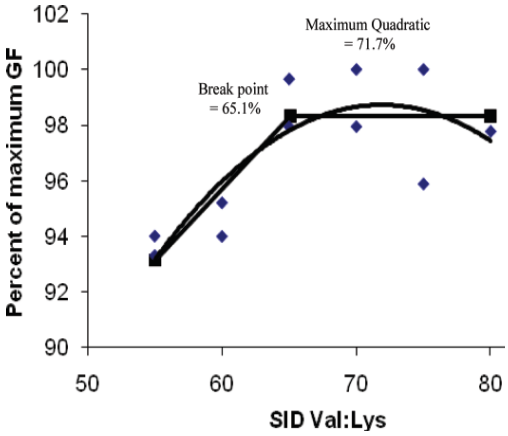


Figure 17 *Fitted linear plateau analysis and quadratic model of average daily gain and gain to feed ratio plotted against SID valine to lysine ratios in 12 to 32 kg growing pigs (Gaines et al., 2011)*

Based on the reviewed literature, we recommend a minimum SID valine to lysine ratio of 67% to optimize average daily gain and feed conversion ratio in growing and finishing pigs. This recommendation is in agreement with the recommendations of Seges Svineproduktion (Tybirk et al., 2016) and NRC (2012) but higher than the recommendation of Ajinomoto Eurolysine S.A.S. (2016).

4.7 Leucine and histidine

Dose-response studies to the SID leucine to lysine ratio and the SID histidine to lysine ratio in growing-finishing pigs have not been published until now. However, recently Gloaguen et al. (2013) conducted six experiments to determine the effect of supplementing a low-CP diet with L-isoleucine, L-histidine and L-leucine on the performance of ad libitum fed piglets weighing 10 to 20 kg. Across experiments, the estimated SID histidine to lysine and SID leucine to lysine ratios for maximizing daily gain were 32% and 102%, respectively, using a curvilinear plateau model. These ratios for SID histidine to lysine and SID leucine to lysine of 32 and 102%, respectively, in weaned piglets are in agreement with those of the INRA (2008) (32 and 100%), NRC (2012) (32% and 101%), Seges Svineproduktion (2016) (32% and 100%) and Ajinomoto Eurolysine (2016) (32% and 100%) in growing and finishing pigs.

Based on the available literature, we recommend a SID leucine to lysine ratio of 100% and a SID histidine to lysine ratio of 32% to optimize average daily gain and feed conversion ratio in growing and finishing pigs.

4.8 Phenylalanine and tyrosine

Dose-response studies to the SID phenylalanine + tyrosine to lysine ratio in growing-finishing pigs have not been published until now. Phenylalanine can be used for tyrosine synthesis and therefore the requirement is usually expressed as the sum of phenylalanine + tyrosine. Recently, Gloaguen et al. (2014) conducted three experiments to estimate the required SID phenylalanine to lysine ratio and SID tyrosine to lysine ratio that maximize feed intake and daily gain in ad libitum fed 10 to 20 kg pigs as well as to determine the extent to which phenylalanine can be used to cover the tyrosine requirement. The estimated SID phenylalanine to lysine and SID tyrosine to lysine ratios for maximizing daily gain were 54% and 40%, respectively, using a curvilinear-plateau model. The replacement of dietary tyrosine by phenylalanine on a molar basis did not maintain growth in the pigs. Therefore, Gloaguen et al. (2014) suggested that the use of a phenylalanine + tyrosine requirement in the ideal protein profile of pigs may need to be reconsidered. They recommend not to use a SID phenylalanine + tyrosine to lysine ratio of 94% but rather use a minimum SID phenylalanine to lysine ratio of 54% and a maximum SID tyrosine to lysine ratio of 40% to support maximal growth. The SID phenylalanine + tyrosine to lysine ratio of 94% in weaned piglets is in agreement with the ratio of the INRA (2008) (95%), NRC (2012) (95-97%), Seges Svineproduktion (2016) (100%) and Ajinomoto Eurolysine (2016) (95%) in growing and finishing pigs.

Based on the available literature, we recommend a SID phenylalanine + tyrosine to lysine ratio of 95% to optimize average daily gain and feed conversion ratio in growing and finishing pigs. Moreover, based on the research of Gloaguen et al. (2014), we recommend a minimum ratio of phenylalanine to phenylalanine + tyrosine of 57%.

5 Updated recommendations for AA

5.1 Updated SID lysine recommendation

In Table 6, the updated recommendations for SID lysine in starter, grower and finisher pig diets for the average current and future growing and finishing boar, gilt and barrow as predicted with InraPorc (Van Milgen et al., 2008) are presented.

Table 6 *Updated recommendations for SID lysine in starter, grower and finisher pig diets (expressed as g/kg, g/MJ NE, g per EW_{2015} and at day 1 of each phase) for the average current and future[1] growing and finishing pig as predicted with Inraporc (Van Milgen et al., 2008)*

	Current growing and Finishing pigs			Future growing and finishing pigs: 10% higher feed intake			Future growing and finishing pigs: 10% improved feed conversion ratio		
	Boar	Gilt	Barrow	Boar	Gilt	Barrow	Boar	Gilt	Barrow
Starter diet (25-50 kg):									
- SID lysine (g/kg)[2]	9.6	9.1	9.1	10.1	9.6	9.6	10.5	9.6	9.8
- SID lysine (g/MJ NE)	0.99	0.94	0.94	1.04	0.99	0.99	1.09	0.99	1.01
- SID lysine (g/EW_{2015})[3]	8.7	8.3	8.3	9.1	8.7	8.7	9.6	8.7	8.9
- SID lysine at 25 kg (d1 of phase 1) (g/d)	11.2	11.0	11.2	12.1	11.7	12.0	11.9	11.5	11.9
Grower diet (50-80 kg):									
- SID lysine (g/kg)[2]	8.4	7.8	7.8	8.60	8.00	7.8	9.4	8.8	8.6
- SID lysine (g/MJ NE)	0.86	0.81	0.81	0.89	0.82	0.81	0.97	0.90	0.89
- SID lysine (g/EW_{2015})[3]	7.6	7.1	7.1	7.8	7.3	7.1	8.5	8.0	7.8
- SID lysine at 50 kg (d1 of phase 1) (g/d)	15.2	14.6	14.9	16.3	16.0	15.8	16.7	16.3	16.3
Finisher diet (80-120 kg)									
- SID lysine (g/kg)[2]	7.5	6.7	6.4	7.5	6.7	6.4	8.4	7.9	7.5
- SID lysine (g/MJ NE)	0.77	0.70	0.66	0.77	0.70	0.66	0.87	0.81	0.77
- SID lysine (g/EW_{2015})[3]	6.8	6.1	5.8	6.8	6.1	5.8	7.6	7.2	6.8
- SID lysine at 80 kg (d1 of phase 1) (g/d)	16.5	15.8	15.0	18.4	17.3	16.4	18.7	17.9	17.4

[1] The daily gain of the future growing and finishing pigs is 10% higher than the daily gain of the current growing and finishing pigs and is realized by a 10% higher feed intake or a 10% improved feed conversion ratio; [2] NE in the diet is 9.68 MJ NE; [3] 1 EW_{2015} = 8.8 MJ NE.

The SID lysine recommendations are higher for boars than for gilts and in general higher for gilts than for barrows. Besides they are mostly higher in the future pigs than in the current pigs.
As discussed in section 3.3, for all three phases (25-50 kg, 50-80 kg and 80-120 kg), the SID lysine requirement at the beginning of the phase is predicted. As the SID lysine requirement per kg of feed declines with age, but the supply per kg of feed remains the same within a phase, an increasing oversupply of SID lysine will be given during each phase. It was calculated that the effect of 5% less SID lysine in the diets on the performance of the current and future boars is relatively small (see Table 4).

On the other hand, it is important to realise that the recommendations in Table 6 are the requirements for an individual pig (the average pig) (Van Milgen et al., 2008). If a herd is fed according to the average pig, only those pigs with a requirement lower than the average pig will be able to express their growth potential, whereas those with a greater potential (half of the herd) will be penalised by offering such a diet (Van Milgen et al., 2008). Brossard et al. (2009) concluded that the SID lysine requirement of a population of pigs is about 10% higher than the SID lysine requirement of the average pig (see Figure 10).
In Table 7, the recommendations for SID lysine in starter, grower and finisher pigs diets for a population of current and future growing and finishing pigs (110% SID lysine supply compared to an average pig) are presented.

Table 7 *Updated recommendations for SID lysine in starter, grower and finisher pig diets (expressed as g/kg, g/MJ NE, g per EW_{2015} and at day 1 of each phase) for a population of current and future[1] growing and finishing pigs; the recommendations for a population of pigs are 10% higher than those for an average pig (Brossard et al., 2009)*

	Current growing and Finishing pigs			Future growing and finishing pigs: 10% higher feed intake			Future growing and finishing pigs: 10% improved feed conversion ratio		
	Boar	Gilt	Barrow	Boar	Gilt	Barrow	Boar	Gilt	Barrow
Starter diet (25-50 kg):									
- SID lysine (g/kg)[2]	10.6	10.1	10.1	11.1	10.6	10.6	11.6	10.6	10.8
- SID lysine (g/MJ NE)	1.09	1.04	1.04	1.15	1.09	1.09	1.19	1.09	1.11
- SID lysine (g/EW_{2015})[3]	9.6	9.1	9.1	10.1	9.6	9.6	10.5	9.6	9.8
- SID lysine at 25 kg (d1 of phase 1) (g/d)	12.3	12.1	12.3	13.3	12.9	13.2	13.1	12.7	13.1
Grower diet (50-80 kg):									
- SID lysine (g/kg)[2]	9.2	8.6	8.6	9.5	8.8	8.6	10.3	9.7	9.5
- SID lysine (g/MJ NE)	0.95	0.89	0.89	0.98	0.91	0.89	1.07	1.00	0.98
- SID lysine (g/EW_{2015})[3]	8.4	7.8	7.8	8.6	8.0	7.8	9.4	8.8	8.6
- SID lysine at 50 kg (d1 of phase 1) (g/d)	16.7	16.1	16.4	17.9	17.6	17.4	18.4	17.9	17.9
Finisher diet (80-120 kg)									
- SID lysine (g/kg)[2]	8.3	7.4	7.0	8.3	7.4	7.0	9.20	8.7	8.3
- SID lysine (g/MJ NE)	0.85	0.76	0.73	0.85	0.76	0.73	0.95	0.90	0.85
- SID lysine (g/EW_{2015})[3]	7.5	6.7	6.4	7.5	6.7	6.4	8.4	7.9	7.5
- SID lysine at 80 kg (d1 of phase 1) (g/d)	18.2	17.4	16.5	20.2	19.0	18.0	20.6	19.7	19.1

[1] The daily gain of the future growing and finishing pigs is 10% higher than the daily gain of the current growing and finishing pigs and is realized by a 10% higher feed intake or a 10% improved feed conversion ratio; [2] NE in the diet is 9.68 MJ NE; [3] 1 EW_{2015} = 8.8 MJ NE.

At a 110% level of SID lysine supply, the simulated performance of most of the pigs in the population will be close to maximum (Brossard et al., 2009). At lower levels of SID lysine supply, the simulated performance will decrease because not all pigs in the population will be fed to their SID lysine requirement. The effect of 5% less SID lysine in the diets on the performance of a population of current and future boars, however, will be relatively small.
To decrease an oversupply of amino acids with only a small negative effect on the performance of a population of pigs, it might be an option to recommend a 5% higher SID lysine level for a population of pigs compared to an average pig. In Table 8, the recommendations for SID lysine in starter, grower and finisher pigs diets for a population of current and future growing and finishing pigs (105% SID lysine supply compared to an average pig) are presented.

Table 8 *Updated recommendations for SID lysine in starter, grower and finisher pig diets (expressed as g per EW_{2015}) for a population of current and future[1] growing and finishing pigs with a 5% higher SID lysine recommendation than an average pig*

	Current growing and Finishing pigs			Future growing and finishing pigs: 10% higher feed intake			Future growing and finishing pigs: 10% improved feed conversion ratio		
	Boar	Gilt	Barrow	Boar	Gilt	Barrow	Boar	Gilt	Barrow
Starter diet (25-50 kg):									
- SID lysine (g/kg)[2]	10.1	9.6	9.6	10.6	10.1	10.1	11.0	10.1	10.3
- SID lysine (g/MJ NE)	1.04	0.99	0.99	1.10	1.04	1.04	1.14	1.04	1.06
- SID lysine (g/EW_{2015})[3]	9.1	8.7	8.7	9.6	9.1	9.1	10.1	9.1	9.3
- SID lysine at 25 kg (d1 of phase 1) (g/d)	11.8	11.6	11.8	12.7	12.3	12.6	12.5	12.1	12.5
Grower diet (50-80 kg):									
- SID lysine (g/kg)[2]	8.8	8.2	8.2	9.0	8.8	8.2	9.9	9.2	9.0
- SID lysine (g/MJ NE)	0.91	0.85	0.85	0.93	0.91	0.85	1.02	0.95	0.93
- SID lysine (g/EW_{2015})[3]	8.0	7.5	7.5	8.2	7.7	7.5	8.9	8.4	8.2
- SID lysine at 50 kg (d1 of phase 1) (g/d)	16.0	15.3	15.6	17.1	16.8	16.6	17.5	17.1	17.1
Finisher diet (80-120 kg)									
- SID lysine (g/kg)[2]	7.9	7.0	6.7	7.9	7.0	6.7	8.8	8.3	7.9
- SID lysine (g/MJ NE)	0.81	0.73	0.69	0.81	0.73	0.69	0.91	0.86	0.81
- SID lysine (g/EW_{2015})[3]	7.1	6.4	6.1	7.1	6.4	6.1	8.0	7.6	7.1
- SID lysine at 80 kg (d1 of phase 1) (g/d)	17.3	16.6	15.8	19.3	18.2	17.2	19.6	18.8	18.3

[1] The daily gain of the future growing and finishing pigs is 10% higher than the daily gain of the current growing and finishing pigs and is realized by a 10% higher feed intake or a 10% improved feed conversion ratio; [2] NE in the diet is 9.68 MJ NE; [3] 1 EW_{2015} = 8.8 MJ NE.

5.2 Updated recommendations for other essential amino acids

In Table 9, the updated recommendations for the levels of SID essential AA other than lysine in starter, grower and finisher pig diets (expressed as % of SID lysine) are presented based on the review in chapter 4. Also, the variation in the SID essential AA to lysine ratio in the literature is presented in Table 9. This variation can partly be explained by the model that is used to predict the SID essential AA to lysine ratio. In general, the predicted ratios are lowest when a linear plateau model is used, whereas they are highest when a quadratic model is used. Moreover, part of the variation can be explained by the used response parameter. In most studies there are differences between the response in daily gain and in feed conversion ratio on an increase in AA supply.

Table 9 *Updated recommendations for SID essential amino acids other than lysine in starter, grower and finisher pig diets (expressed as % of SID lysine) for current and future[1] growing and finishing pigs and the variation in the SID essential amino acid to lysine ratios in the reviewed literature*

	Starter diet (25-50 kg)	Grower diet (50-80 kg)	Finisher diet (80-120 kg)	Variation in ratios in reviewed literature
Lysine	100	100	100	
Methionine+Cystine[2]	60	61	62	58-63
Threonine	66	67	68	61-74
Tryptophan	20	20	20	17-23
Isoleucine[3]	53	53	53	50-54
Valine	67	67	67	64-72
Leucine[4]	100	100	100	100-102
Histidine[4]	32	32	32	32-32
Phenylalanine+Tyrosine[4,5]	95	95	95	94-100

[1] The daily gain of the future growing and finishing pigs is 10% higher than the daily gain of the current growing and finishing pigs and is realized by a 10% higher feed intake or a 10% improved feed conversion ratio;

[2] A minimum ratio of methionine to methionine+cystine of 55% is advised;

[3] Recommendation in diets without blood products (non-excess level of leucine);

[4] Based on experiments with weaned piglets;

[5] A minimum SID phenylalanine to lysine of 54 % and a maximum SID tyrosine to lysine ratio of 40% to support maximal growth is advised (Gloaguen et al., 2014).

References

AgroVision. 2017. Kengetallenspiegel 2016. Bedrijfsvergelijking AgroVision B.V.

Ajinomoto Eurolysine S.A.S. 2008. Threonine in pigs and broilers. A crucial amino acid for growht and gut function. Information bulletin 31.

Ajinomoto Eurolysine S.A.S. 2012. Estimating amino acid requirements through dose-response experiments in pigs and poultry. Protocol and results interpretation. Technical note, February.

Ajinomoto Eurolysine S.A.S. 2016. Ideal amino acid profile and low crude protein diets for fattening pigs.

Baker, D.H. 1986. Problems and pitfalls in animal experiments designed to establish dietary requirements for essential nutrients. Journal of Nutrition 116, 2339–2349.

Blok, M.C., G. Brandsma, G. Bosch, W.J.J. Gerrits, A.J.M. Jansman and J. Fledderus, H. Everts. 2015. A new dutch net energy formula for feed and feedstuffs for growing and fattening pigs. CVB-Documentation Report nr. 56.

Brossard, L., J.Y. Dourmad, J. Rives and J. van Milgen. 2009. Modelling the variation in performance of a population of growing pigs as affected by lysine supply and feeding strategy. Animal, 3, 114-1123.

CVB. 1996. Aminozuurbehoefte van biggen en vleesvarkens. CVB documentatierapport nr. 14.

CVB. 2016a. Tabellenboek Veevoeding 2016. Voedernormen varkens en voederwaarden voedermiddelen voor varkens.

CVB. 2016b. CVB Veevoedertabel 2016. Chemische samenstellingen en nutritionele waarden van voedermiddelen.

Gaines A.M., D.C. Kendall, G.L. Allee, J.L. Usry and B.J. Kerr. 2011. Estimation of the standardized ileal digestible valine to lysine ratio in 13 to 32 kg pigs. J. Anim. Sci., 89:736–742.

Gaines A.M., G.F. Yi, B.W. Ratliff, P. Srichana, G.L. Alle, C.D. Knight, and K.P. Perryman. 2004. Estimation of the true ileal digestible sulfur amino acid : lysine ratio for growing pigs weighing 29–45 kilograms. Journal of Animal Science, 83 (Suppl. 1), 294.

Gillis A.M., A. Reijmers, J.R. Pluske and C.F.M. de Lange. 2007. Influence of dietary methionine to methionine plus cysteine ratios on nitrogen retention in gilts fed purified diets between 40 and 80 kg live body weight. Canadian Journal of Animal Science, 87:87–92.

Gloaguen, M., N. Le Floc'h, Y. Primot, E. Corrent, and J. van Milgen. 2013. Response of piglets to the standardized ileal digestible isoleucine, histidine and leucine supply in cereal-soybean meal-based diets. Animal 7(6):901-908.

Gloaguen, M., N. Le Floc'h, Y. Primot, E. Corrent, and J. van Milgen. 2014b. Performance of piglets in response to the standardized ileal digestible phenylalanine and tyrosine supply in low-protein diets. Animal 8(9):1412-1419.

Hahn, J.D. and D.H. Baker. 1995. Optimum ratio to lysine of threonine, tryptophan, and sulfur amino acids for finishing swine. Journal of Animal Science, 73, 482–489.

Htoo, J.K., C.L. Zhu, L. Huber, C.F.M. de Lange, A.D. Quant, B.J. Kerr, G.L. Cromwell, and M.D. Lindemann. 2014. Determining the optimal isoleucine:lysine ratio for ten- to twenty-two-kilogram and twenty-four- to thirty-nine-kilogram pigs fed diets containing nonexcess levels of leucine. J. Anim. Sci. 92:3482–3490

Liu, X. T., W. F. Ma, X. F. Zeng, C. Y. Xie, P. A. Thacker, J. K. Htoo, and S. Y. Qiao. 2015. Estimation of the standardized ileal digestible valine to lysine ratio required for 25-to 120-kilogram pigs fed low crude protein diets supplemented with crystalline AA. J. Anim. Sci. 93(10):4761-4773.

Ma, W., J. Zhu, X. Zeng, X. Liu, P. Thacker, and S. Qiao. 2016. Estimation of the optimum standardized ileal digestible total sulfur amino acid to lysine ratio in late finishing gilts fed low protein diets supplemented with crystalline AA. Anim. Sci. J. 87(1):76-83.

Ma, W. F., X. F. Zeng, X. T. Liu, C. Y. Xie, G. J. Zhang, S. H. Zhang, and S. Y. Qiao. 2015a. Estimation of the standardized ileal digestible lysine requirement and the ideal ratio of threonine to lysine for late finishing gilts fed low crude protein diets supplemented with crystalline AA. Anim. Feed Sci. Technol. 201:46-56.

Ma, W. F., S. H. Zhang, X. F. Zeng, X. T. Liu, C. Y. Xie, G. J. Zhang, and S. Y. Qiao. 2015b. The appropriate standardized ileal digestible tryptophan to lysine ratio improves pig performance and regulates hormones and muscular amino acid transporters in late finishing gilts fed low-protein diets. J. Anim. Sci. 93(3):1052-1060.

Millet, S., M. Aluwé, E. Le Gall, E. Corrent, J. de Sutter, B. Ampe and S. de Campeneere. 2015. Le besoin en tryptophane des porcs en croissance (20 - 55 kg). Journées Recherche Porcine, 47, 137-138.
NRC. 2012. Nutrient requirements of swine. 11th Revised edition, National Academy Press, Washington, DC.
Qiao S., X. Piao, Z. Feng, Y. Ding, L. Yue, P.A. Thacker. 2008. The optimum methionine to methionine plus cystine ratio for growing pigs determined using plasma urea nitrogen and nitrogen balance. Asian-Australasian Journal of Animal Sciences, 21, 434–442.
Peak S. (2005): TSAA requirement for nursery and growing pigs. In: Foxcroft G. (ed.): Advances in Pork Production. University of Alberta Press, Edmonton, Canada, 101–107.
Peet-Schwering, C.M.C. van der, S.B. Straathof, G.P. Binnendijk and J.Th.M. van Diepen. 2012. Influence of diet composition and level of AA on performance of boars, barrows and gilts. Rapport 563 [in Dutch], Wageningen Livestock Research, Wageningen.
Pomar C., I. Kyriazakis, G.C. Emmans, and P.W. Knap. 2003. Modeling stochasticity: dealing with populations rather than individual pigs. Journal of Animal Science, 81, E178–E186.
Robbins, K.K., A. M. Saxton, and L. L. Southern. 2006. Estimation of nutrient requirements using broken-line regression analysis. J. Anim. Sci., 84 (E. Suppl):E155-E165.
Simongiovanni A., E. Corrent, N. Le Floc'h and J. van Milgen. 2013. Le besoin en tryptophane des porcs charcutiers. Journées Recherche Porcine, 45, 163-164.
Tybirk, P., N. Morten Sloth, N. Kjeldsen and L. Shooter. 2016. Nutrient requirement standards for pigs in Denmark; the 26th edition of the Danish nutrient standards. Seges Pig Research Centre.
Van Milgen, J.M., A. Valancogne, S. Dubois, J.Y. Dourmad, B. Sève and J. Noblet. 2008. InraPorc: A model and decision support tool for the nutrion of growing pigs. Animal Feed Science and Technology, 143, 387-405.
Van Milgen, J.M., M. Gloaguen, N. Le Floc'h, L. Brossard, Y. Orimot and E. Corrent. 2012. Meta-analysis of the response of growing pigs to the isoleucine concentration in the diet. Animal, 6, 1601-1608.
Van Milgen, J.M. and J.Y. Dourmad. 2015. Concept and application of ideal protein for pigs. Journal of Animal Science and Biotechnology 6, 15-25.
Waguespack, A.M., T.D. Bidner, R.L Payne and L.L. Southern. 2012. Valine and isoleucine requirement of 20- to 45-kilogram pigs. J. Anim. Sci. 93:2276-2284.
Xie, C., S. Zhang, G. Zhang, F. Zhang, L. Chu, and S. Qiao. 2013. Estimation of the optimal ratio of standardized ileal digestible threonine to lysine for finishing barrows fed low crude protein diets. Asian-Australas. J. Anim. Sci. 26(8):1172-1180.
Xie, C.Y., G.J. Zhang, F.R. Zhang, S.H. Zhang, X.F. Zeng, P.A. Thacker, and S.Y. Qiao. 2014. Estimation of the optimal ratio of standardized ileal digestible tryptophan to lysine for finishing barrows fed low protein diets supplemented with crystalline AA. Czech J. Anim. Sci. 59(1):26-34.
Yi G.F., A.M. Gaines, B.W. Ratliff, P. Srichana, G.L. Alle, C.D. Knight, and K.P. Perryman. 2005. Estimation of the true ileal digestible sulfur amino acid : lysine ratio for growing pigs weighing 28–49 kilograms. Journal of Animal Science, 83 (Suppl. 1), 213.
Zhang, G.J., Q.L. Song, C.Y. Xie, L.C. Chu, P.A. Thacker, J.K. Htoo, and S.Y. Qiao. 2012. Estimation of the ideal standardized ileal digestible tryptophan to lysine ratio for growing pigs fed low crude protein diets supplemented with crystalline AA. Livest. Sci. 149(3):260-266.
Zhang, G.J., C.Y. Xie, P.A. Thacker, J.K. Htoo, and S.Y. Qiao. 2013. Estimation of the ideal ratio of standardized ileal digestible threonine to lysine for growing pigs (22–50 kg) fed low crude protein diets supplemented with crystalline AA. Anim. Feed Sci. Technol. 180:83–91.
Zhang, G.J., P.A. Thacker, J.K. Htoo, and S.Y. Qiao. 2015. Optimum proportion of standardised ileal digestible sulphur amino acid to lysine to maximize the performance of 25–50 kg growing pigs fed reduced crude protein diets fortified with AA. Czech J. Anim. Sci. 60 (7), 302-310.

Appendix 1 Daily SID lysine requirement

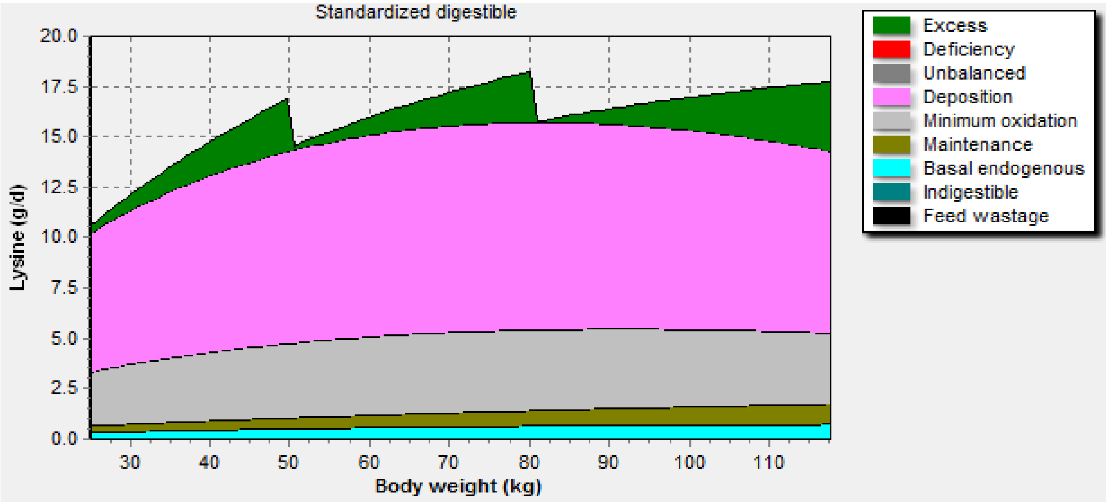


Figure 1a *Daily SID lysine required for maintenance and protein deposition and daily excess of SID lysine for the current growing and finishing gilt (current CVB -10% lysine in finisher diet)*

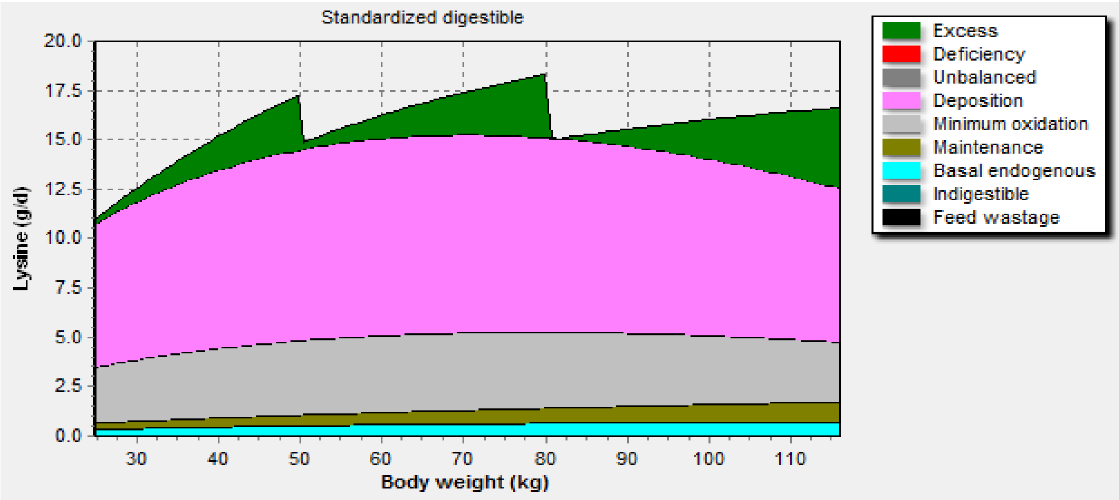


Figure 1b *Daily SID lysine required for maintenance and protein deposition and daily excess of SID lysine for the current growing and finishing barrow (current CVB -15% lysine in finisher diet)*

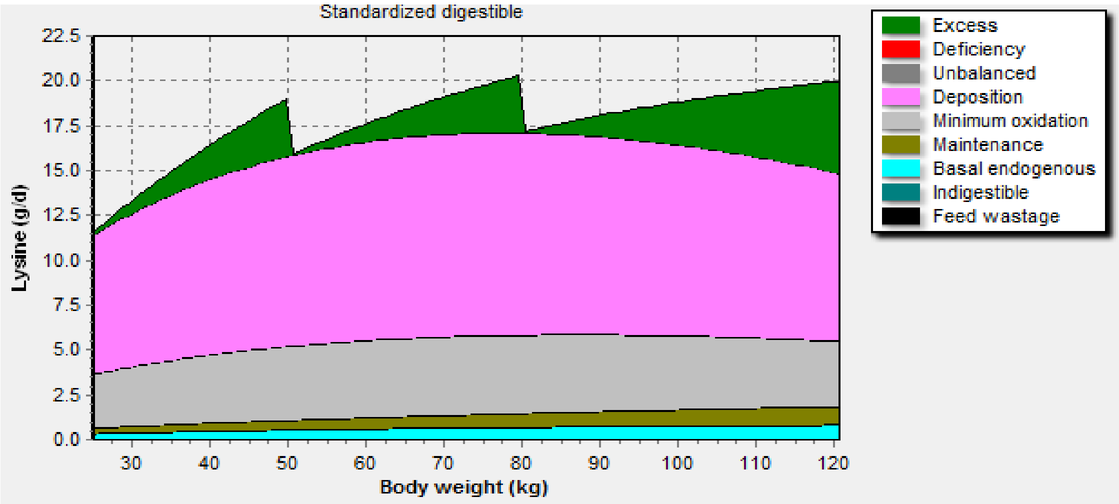


Figure 2a *Daily SID lysine required for maintenance and protein deposition and daily excess of SID lysine for the future (10% higher daily gain and feed intake) growing and finishing gilt (current CVB +5% lysine in starter diet, +2% lysine in grower diet and -10% in finisher diet)*

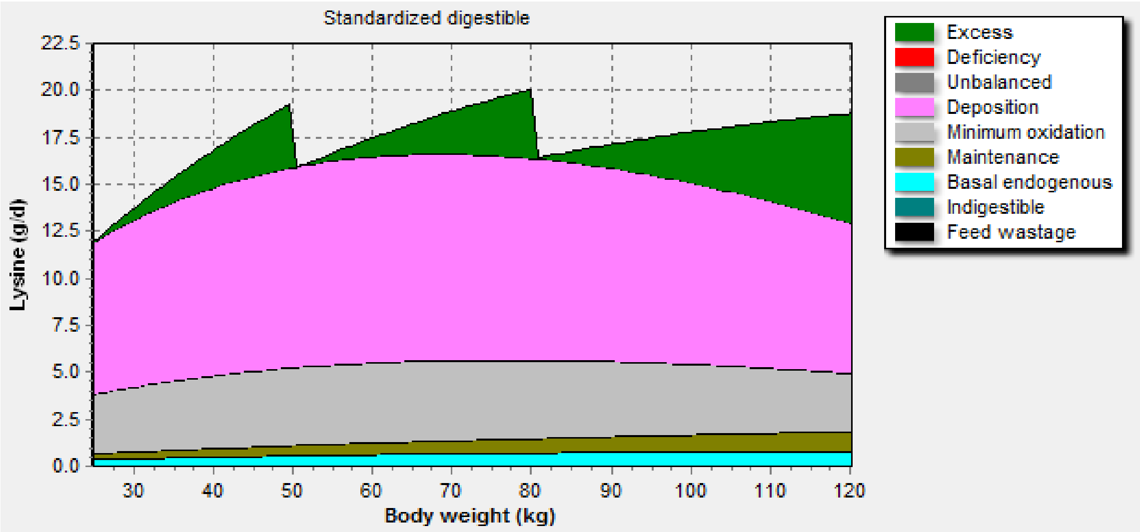


Figure 2b *Daily SID lysine required for maintenance and protein deposition and daily excess of SID lysine for the future (10% higher daily gain and feed intake) growing and finishing barrow (current CVB +5% lysine in starter diet and -15% lysine in finisher diet)*

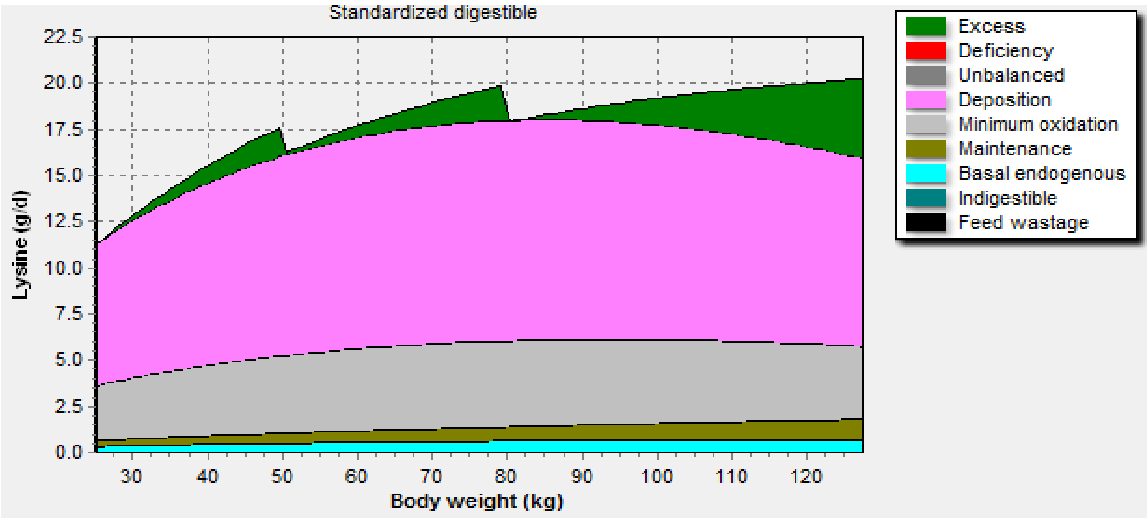


Figure 3a *Daily SID lysine required for maintenance and protein deposition and daily excess of SID lysine for the future (10% higher daily gain and improved feed conversion ratio) growing and finishing gilt (current CVB +5% lysine in starter diet, +12% lysine in grower diet and +5% in finisher diet)*

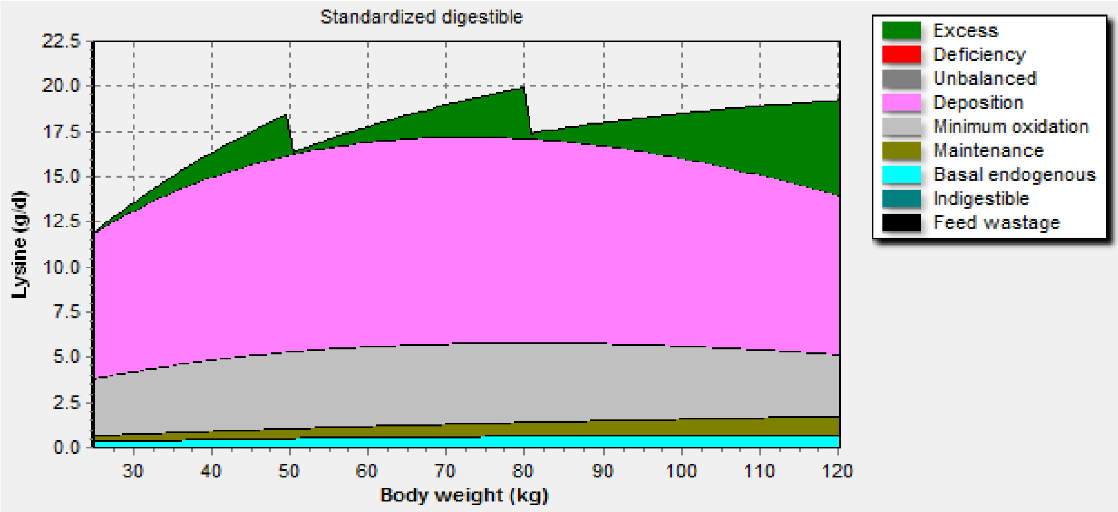


Figure 3b *Daily SID lysine required for maintenance and protein deposition and daily excess of SID lysine for the future (10% higher daily gain and improved feed conversion ratio) growing and finishing barrow (current CVB +7% lysine in starter diet and +10% lysine in grower diet)*

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Wageningen Livestock Research Postbus 338
6700 AH Wageningen
T 0317 48 39 53
E info.livestockresearch@wur.nl www.wur.nl/livestock-research

Wageningen Livestock Research ontwikkelt kennis voor een zorgvuldige en renderende veehouderij, vertaalt deze naar praktijkgerichte oplossingen en innovaties, en zorgt voor doorstroming van deze kennis. Onze wetenschappelijke kennis op het gebied van veehouderijsystemen en van voeding, genetica, welzijn en milieu-impact van landbouwhuisdieren integreren we, samen met onze klanten, tot veehouderijconcepten voor de 21e eeuw.

De missie van Wageningen University & Research is 'To explore the potential of nature to improve the quality of life'. Binnen Wageningen University & Research bundelen 9 gespecialiseerde onderzoeksinstituten van Stichting Wageningen Research en Wageningen University hun krachten om bij te dragen aan de oplossing van belangrijke vragen in het domein van gezonde voeding en leefomgeving. Met ongeveer 30 vestigingen, 6.500 medewerkers en 10.000 studenten behoort Wageningen University & Research wereldwijd tot de aansprekende kennisinstellingen binnen haar domein. De integrale benadering van de vraagstukken en de samenwerking tussen verschillende disciplines vormen het hart van de unieke Wageningen aanpak.