Standardized ileal digestible threonine requirement for laying hens

J.W. Spek

Wageningen Livestock Research

CVB Documentation report nr. 71
June 2018

https://doi.org/10.18174/455521

Wageningen Livestock Research
P.O. Box 338
6700 AH Wageningen
The Netherlands

Preface

In 2017 a new Table has been introduced called; Table 'Standardized ileal digestibility of amino acids in feedstuffs for poultry' and has been described in the CVB Documentation report nr. 61. As a feed evaluation system has two pillars – the supply of nutrients by the diet on the one hand and the requirement for these nutrients by the animals on the other hand (both expressed in the same units) – it was also necessary to also update and express the amino acid requirements on a standardized ileal digestibility (SID) basis.
Therefore a large meta-analysis dataset was constructed from studies in which amino acid requirements in laying hens were estimated. The SID amino acid concentrations of the diets used in these studies were recalculated based on the new CVB SID amino acid Table presented in CVB documentation report nr. 61 and the requirement for SID threonine was subsequently estimated. The results of this meta-analysis for standardized ileal digestible threonine (SID-THR) requirement are presented in the present CVB Documentation report.
Compared to the former CVB apparent faecal digestible THR recommendation for laying hens described in CVB Documentation report nr. 18 and published in 1996 the present established SID-THR amino acid recommendations for laying hens are:

1. Based on a larger dataset of requirement studies
2. Based on studies with modern laying hen types in the period 1990 – 2017
3. Based on standardized ileal digestible amino acid values in feedstuffs instead of apparent faecal digestible amino acid values.

The in this report estimated requirements of SID-THR will be incorporated in the Dutch CVB Tabellenboek Veevoeding Pluimvee 2018 and in the English version CVB Table Poultry Nutrition 2018.

This study was guided and assessed by the Technical Committee of CVB and the Ad hoc group 'SID amino acid requirements for laying hens'

Wageningen, June 2018

J.W. Spek

Members of the Technical Committee of the CVB

M. Rijnen (chair)	Nederlandse Vereniging Diervoederindustrie (Nevedi)
J. Fledderus	Nederlandse Vereniging Diervoederindustrie (Nevedi)
B. Boswerger	Nederlandse Vereniging Diervoederindustrie (Nevedi)
A. Dijkslag	Nederlandse Vereniging Diervoederindustrie (Nevedi)
H. van Laar	Nederlandse Vereniging Diervoederindustrie (Nevedi)
K. Geerse	Nederlandse Vereniging Diervoederindustrie (Nevedi)
D. van Manen	Overleggroep Producenten Natte Veevoeders (OPNV)
J. van der Staak	Land- en Tuinbouworganisatie Nederland (LTO)
H. Korterink	Nederlandse Vereniging van Handelaren in Stro, Fourages en Aanverwante Producten (HISFA)
A. van de Ven	Nederlandse Vereniging Diervoederindustrie (Nevedi)
C. van Vuure	MVO, ketenorganisatie voor oliën en vetten
G. van Duinkerken	Wageningen Livestock Research, Dept. Animal Nutrition, Wageningen
J.W. Spek	Wageningen Livestock Research, Dept. Animal Nutrition, Wageningen

Members of the Ad hoc group 'SID amino acid requirements for laying hens'

A. Dijkslag	ForFarmers, Lochem
M. van Erp	De Heus, Ede
K. Geerse	Trouw Nutrition, Amersfoort
A. de Ruijter	De Hoop, Zelhem
J.W. Spek	Wageningen Livestock Research, Wageningen
B. Swart	Agrifirm, Apeldoorn

Contents

Abbreviations

AA	Amino acids
AFD	Apparent faecal digestible
ARG	Arginine
BW	Body weight
BWG	Body weight gain
CP	Crude protein
CYS	Cysteine
EM	Egg mass
FCR	Feed conversion ratio
ILE	Isoleucine
LYS	Lysine
Max	Maximum value
ME	Metabolic energy
MElh	Metabolic energy for laying hens
MET	Methionine
Min	Minimum value
M+C	Methionine plus Cysteine
N	Number
R^2	Coefficient of determination
Req.	Requirement
SID	Standardized ileal tract digestible
Std. Dev.	Standard deviation
Std. Err.	Standard error
THR	Threonine
TRP	Tryptophan
VAL	Valine
%CV	Coefficient of variation

1 Introduction

In 2012 a large meta-analysis was carried out by van Krimpen and others in order to determine the dietary requirements for standardized ileal tract digestible (SID) amino acids (AA) for laying hens. This study resulted in a report published by van Krimpen et al. (2015). Before the start of this meta-analysis another large meta-analysis was carried out in order to determine the SID-AA levels for the various feed ingredients. This meta-analysis resulted in a CVB table with SID-AA concentrations for the various feed ingredients and this Table was used by van Krimpen et al. (2015) in order to recalculate the dietary SID-AA levels for the individual AA titration studies in order to estimate AA requirements. However, in 2017 this CVB Table has been updated with new data published in the years between 2012 and 2017 as there were questions about the SID cysteine digestibility value for soybean meal. As a result, not only the SID-AA values for soybean meal have been updated but also for other feedstuffs. As a consequence it was necessary to recalculate all the diets used in the AA titration studies that van Krimpen et al. (2015) used to determine AA-requirements. In this study the results of estimated dietary SID threonine (SID-THR) requirements based on the new Table values as presented in CVB documentation report nr. 61 are presented. Furthermore, the dataset used by van Krimpen et al. has been extended with new studies that were not included in the study of van Krimpen et al..

Furthermore, compared to the study of van Krimpen another model for estimation of SID-THR requirements has been used. This model consisted of a quadratic broken-line model as described and used in the estimation of SID-LYS requirements for laying hens as well (CVB documentation report nr. 69).

2 Materials and Methods

Threonine requirement studies were selected from literature (1990 – 2017) in which the dietary THR content was varied by means of addition of graded levels of dietary synthetic THR. Furthermore, performance characteristics such as egg mass (EM: g/d/hen) and feed conversion ratio (FCR; g feed : g egg mass) had to be recorded and information with respect to dietary composition and age of the laying hens had to be provided in the studies. The apparent faecal digestible (AFD) non-test-AA : AFD-LYS ratios needed to be at least 90% of the CVB (2012) requirement level and the basal AFD-THR : AFD-LYS ratio needed to be at least 20% below the CVB (2012) AFD-THR : AFD-LYS requirement level. Also studies were considered in which the THR requirement was investigated based on summit and dilution diets that were mixed in various ratios in order to obtain the desired differences in THR.

Requirements were estimated using a quadratic broken-line model as described below. This model was adopted from a publication of Robbins et al. (2006).

The quadratic broken-line model is as follows:

If (SID-THR (%) < R) then EM or FCR = L + U × (R – SID-THR)$^{\wedge 2}$;
Else EM or FCR = L + U × 0;
Where:
L = plateau value for EM or FCR
R = break-point value for SID-THR (%)
U = slope value, representing the increase in EM or decrease in FCR per unit increase in dietary SID-THR.

Estimated SID-THR requirements for EM and FCR were regressed against factors such as EM, FCR, age, and the dietary factors CP, ME and CP : ME ratio.

3 Results and Discussion

In Table 1. Some characteristics of the studies included in the meta-analysis is given. The dataset consisted of 7 studies with in total 10 trials and 56 observations. Of these studies, 6 studies (including 9 trials) were titration trials and one study (including one trial; the study of Huyghebaert and Butler; 1991) made use of a summit and dilution diet.

In Appendix A for each titration trial the relationship between dietary SID-THR (%) and FCR and between dietary SID-THR (%) and EM is presented graphically together with the estimated SID-THR requirement for the quadratic broken-line model.
In Appendix B the estimated quadratic broken-line model parameters for each titration trial is given. In one case (for trial 5) also model estimates are provided in case the treatments with the lowest four dietary SID-THR concentrations were removed as it was expected that for this trial this would significant affect model estimates of R (or requirement estimates for SID-THR). The model predictions for this trial where the 4 lowest dietary SID-THR treatments were removed prior to fitting the model are shown with the letter "a" (i.e. trial 5 becomes trial 5a).

For a number of titration trials it was not possible to estimate (unique) SID-THR requirements for maximum EM (for trials 8 and 10) and for minimum FCR (for trials 8, and 9).

Most titration trials (trials 1, 2, 6, 7, 8, 9 and 10) had a sharp defined optimal dietary SID-THR concentration for maximum EM and minimum FCR with reduced performance at lower and higher dietary SID-THR concentrations. The curve fitting model, however, is not suited to also account for a decline in performance after an optimum has been reached and might therefore result in requirement estimates that are not accurate. It was therefore decided to also consider the observed optimal dietary SID-THR concentrations (i.e. the dietary SID-THR levels at which maximum EM was observed in the individual trials) alongside the model estimated optimal dietary SID-THR concentrations.

In Table 2 the average estimated and observed optimal SID-THR concentrations and SID-THR intake statistics for maximum EM are presented in which also is distinguished between titration trials and dilution diets.

For the basal diets used in the study of Ishibashi et al. (1997) it was observed that calculated SID-TRP levels were below recommended digestible TRP:LYS ratios. The in the study of Ishibashi calculated dietary TRP concentration of the basal diet was 0.38% and substantially above NRC (1994) requirements. The calculated TRP level using CVB data was 0.086%. Comparing the CVB data with NRC data it was observed that the difference could be fully ascribed to differences in TRP concentrations for sorghum. In the NRC, the TRP concentration for sorghum was 0.8% whereas in CVB this is 0.1%. The Feedipedia website also presents TRP concentrations of 0.1% for sorghum. We think it is likely that the NRC is wrong with respect to the TRP concentration of sorghum. Therefore it was chosen to present the data in Table 2 another time but then excluding the data of Ishibashi et al. (1997). The results excluding the data of Ishibashi are shown in Table 3 for the estimated SID-THR requirements (i.e. the estimated requirements based on the model outcomes) and in Table 4 for the observed SID-THR requirements (i.e. the SID-THR level at which maximum EM and minimum FCR was observed in the trials).

Table 1. Summary of the total dataset

Study	Trial	Breed	Starting Age (weeks)	Duration of experiment (weeks)	Dietary CP (%)	Max obs. rate of lay (%)	Max obs. egg mass	Max obs. feed intake	Min SID-THR (%)	Max SID-THR (%)	Max. FCR minus Min. FCR	Max. egg mass minus Min. egg mass
Cupertino et al. (2010)	1	Lohman LSL	54	16	13.1	79	52	111	0.356	0.487	0.300	7.9
	2	Lohman Brown	54	16	13.1	76	51	111	0.356	0.487	0.210	6.3
Sá et al. (2007)	3	Lohman	34	16	14.2	85	54	117	0.377	0.517	0.277	4.3
	4	Lohman Brown	34	16	14.2	88	57	114	0.377	0.517	0.353	7.2
Huyghebaert and Butler (1991)*	5	ISA Brown	28	10	9.0	87	53	128	0.198	0.397	2.790	37.4
Schmidt et al. (2010)	6	Lohman Brown	79	16	13.1	69	48	110	0.344	0.476	0.258	5.4
Schmidt et al. (2011)	7	Lohman Brown	79	16	13.1	71	48	108	0.344	0.476	0.220	4.7
da Rocha et al. (2013)	8	Hy-line W36	24	16	14.2	85	48	94	0.443	0.625	0.080	3.8
Ishibashi et al. (1997)	9	Dekalb XL	29	3	14.4		54	107	0.275	0.575	0.138	4.1
	10	Dekalb XL	39	8	14.4		53	116	0.275	0.475	0.058	4.6

*Study with an asterix is a dilution study meaning that AA other than THR changed as well alongside THR.

Table 2. Estimated and observed optimal SID-THR requirements (% and daily intake) for maximum egg mass (EM).

	Parameter	N	Mean	Std. Dev.	Min.	Max.	%CV
Estimated SID-THR (%)	Titration*	7	0.416	0.0220	0.378	0.436	5.3
	Dilution**	1	0.347				
Observed SID-THR (%)	Titration*	9	0.446	0.0432	0.375	0.516	9.7
	Dilution**	1	0.375				
Estimated SID-THR intake (mg/d)	Titration*	7	457	32.4	400	487	7.1
	Dilution**	1	438				
Observed SID-THR intake (mg/d)	Titration*	9	483	38.4	434	542	7.9
	Dilution**	1	468				
Estimated SID-THR intake per g of EM (mg/g)	Titration*	7	9.0	0.67	7.6	9.5	7.5
	Dilution**	1	8.5				
Observed SID-THR intake per g of EM (mg/g)	Titration*	9	9.4	0.72	8.2	10.1	7.7
	Dilution**	1	8.9				
Observed SID-THR:SID-LYS ratio	Titration*	9	64.5	6.62	50.7	71.1	10.3
	Dilution**	1	39.9				
Observed SID-THR:SID-LYS ratio***	Titration*	9	67.9	7.49	59.8	84.8	11.0
	Dilution**	1	66.1				
Estimated SID-THR:SID-LYS ratio***	Titration*	7	63.3	3.86	55.7	66.6	6.1
	Dilution**	1	64.9				

* Total number of titration trials is 9. For two titration trials it was not possible to estimate unique SID-THR requirements resulting in a total of 7 titration trials that could be used for estimated SID-THR requirements.

**There was only one dilution trial from the study of Huyghebaert and Butler (1991). The estimated requirement is based on the results in which the four lowest dietary SID-THR treatments were excluded from the analysis.

***This ratio is calculated using formula [F8] in documentation report nr. 69 to predict SID-LYS requirement. In case the formula [F8] resulted in a lower SID-LYS requirement than the observed SID-LYS intake at which maximum EM was estimated, then this formula was used to calculate the SID-THR:SID-LYS ratio, otherwise the observed SID-LYS intake at which maximum EM was estimated was used.

Table 3. Estimated optimal SID-THR requirements (% and daily intake) for maximum egg mass (EM).

	Parameter	**N**	**Mean**	**Std. Dev.**	**Min.**	**Max**	**%CV**
SID-THR (%)	Titration*	6	0.422	0.0160	0.391	0.436	3.8
	Dilution**	1	0.347				
SID-THR intake (mg/d)	Titration*	6	466	22.4	426	487	4.8
	Dilution**	1	438				
SID-THR intake per g of EM (mg/g)	Titration*	6	9.2	0.28	8.8	9.5	3.0
	Dilution**	1	8.5				
SID-THR:SID-LYS ratio	Titration*	6	63.0	2.37	60.1	65.8	3.8
	Dilution**	1	39.9				
SID-THR:SID-LYS ratio***	Titration*	6	64.6	2.03	61.5	66.6	3.1
	Dilution**	1	64.9				

* Total number of titration trials is 9. For two titration trials it was not possible to estimate unique SID-THR requirements. Furthermore, results from two titration trial from the study of Ishibashi et al. (1997) were excluded resulting in a total of 6 titration trials that could be used for estimated SID-THR requirements.

**There was only one dilution trial from the study of Huyghebaert and Butler (1991). The estimated requirement is based on the results in which the four lowest dietary SID-THR treatments were excluded from the analysis.

***This ratio is calculated using formula [F8] in CVB documentation report nr. 69 to predict SID-LYS requirement. In case the formula [F8] resulted in a lower SID-LYS requirement than the observed SID-LYS intake at which maximum EM was estimated, then this formula was used to calculate the SID-THR:SID-LYS ratio, otherwise the observed SID-LYS intake at which maximum EM was estimated was used.

Table 4. Observed optimal SID-THR requirements (% and daily intake) at which maximum egg mass (EM) was observed.

	Parameter	**N**	**Mean**	**Std. Dev.**	**Min.**	**Max**	**%CV**
SID-THR (%)	Titration*	7	0.459	0.0374	0.410	0.516	8.2
	Dilution**	1	0.375				
SID-THR intake (mg/d)	Titration*	7	494	35.8	448	542	7.2
	Dilution**	1	468				
SID-THR intake per g of EM (mg/g)	Titration*	7	**9.7**	0.42	9.0	10.1	4.3
	Dilution**	1	8.9				
SID-THR:SID-LYS ratio	Titration*	7	67.5	2.74	63.5	71.1	4.1
	Dilution**	1	39.9				
SID-THR:SID-LYS ratio***	Titration*	7	70.0	7.14	63.5	84.8	10.2
	Dilution**	1	66.1				

* Total number of titration trials is 9. For two titration trials it was not possible to estimate unique SID-THR requirements. Furthermore, results from two titration trial from the study of Ishibashi et al. (1997) were excluded resulting in a total of 7 studies for observed SID-THR requirements (i.e. the SID-THR levels at which maximum egg mass production was observed).

**There was only one dilution trial from the study of Huyghebaert and Butler (1991).

***This ratio is calculated using formula [F8] in CVB documentation report nr. 69 to predict SID-LYS requirement. In case the formula [F8] resulted in a lower SID-LYS requirement than the observed SID-LYS intake at which maximum EM was estimated, then this formula was used to calculate the SID-THR:SID-LYS ratio, otherwise the observed SID-LYS intake at which maximum EM was estimated was used.

Results in Table 3 and 4 show that the observed optimal SID-THR requirements based on the titration experiments are little higher than the estimated SID-THR requirements. Furthermore, the range in estimated SID-THR requirements (expressed as %, in mg per g of EM and as a % of SID-LYS) is smaller for the estimated SID-THR requirements compared to the observed SID-THR requirements.

In the average values presented in Table 3 and 4 no selection is made with respect to observations from trials with low maximum egg production rates. The reason for this is the consideration that there are only few observations and that, for example, leaving out the observations with egg production rates lower than 80% would reduce the dataset by 50%. In case the two observations with the lowest egg production rates would be excluded from the dataset (studies of Schmidt et al. 2010 and Schmidt et al. 2011), this did not result in changed estimated SID-THR requirements. For example, the observed optimal SID-THR intake per g of EM of 9.7 mg and the estimated SID-THR optimal SID-THR intake per g of EM of 9.2 intake remained the same.

The requirement for dietary SID-THR for EM production was also estimated directly on the data from Huyghebaert and Butler (1991) (Fig. 1). Results from Fig. 1 indicate a requirement of 8.5 mg SID-THR per g of EM.

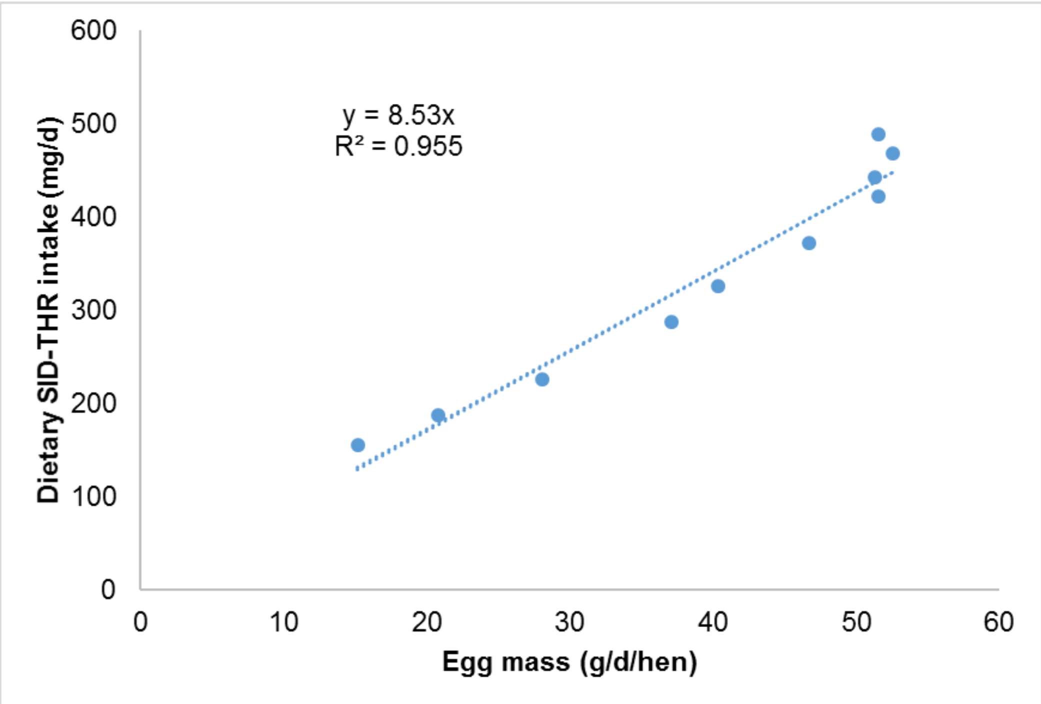


Figure 1. Relationship between egg mass produced (mg/d/hen) and dietary SID-THR intake for the dataset of Huyghebaert and Butler (1991).

A strong negative association was observed between observed dietary SID-THR concentration at minimum FCR and the minimum FCR itself (Fig. 2). As well, a negative association was observed between the estimated dietary SID-THR requirement for minimum FCR and the corresponding FCR (also presented in Fig. 2).

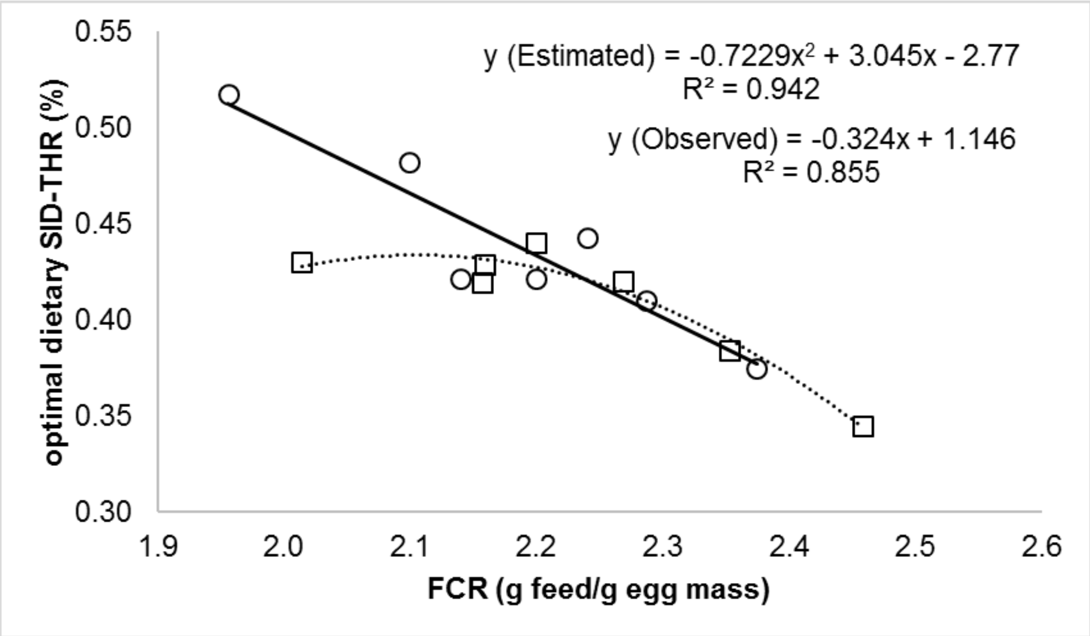


Figure 2. Relationship between observed dietary SID-THR concentration at minimum FCR and FCR itself (circles and solid line). Relationship between estimated dietary SID-THR requirement for minimum FCR and the corresponding FCR (squares, dotted line). Based on trials 1, 2, 3, 4, 5, 6 and 7.

In Table 5 the optimal SID-THR requirements are given for maximum EM expressed in mg/d and as a percentage of the diet for maximum EM at various egg production rates based on SID-THR requirements of 9.7 gram of EM produced corresponding with the observed SID-THR requirements per gram of EM as shown in Table 4.

In Table 6 theoptimal SID-THR requirements are given for maximum EM expressed in mg/d and as a percentage of the diet for maximum EM at various egg production rates based on SID-THR requirements of 9.2 gram of EM produced corresponding with the estimated SID-THR requirements per gram of EM as shown in Table 3.

In Table 7 the optimal SID-THR requirements are given for minimum FCR expressed in mg/d and as a percentage of the diet for minimum FCR at various egg production rates based on the relationship between observed SID-THR at minimum observed FCR and the corresponding FCR as shown in Figure 2 by the solid line.

Table 5. Optimal SID-THR requirements for maximum EM expressed in mg/d and as a percentage of the diet for maximum EM at various egg production rates based on SID-THR requirements of 9.7 mg per gram of EM produced corresponding with the observed SID-THR requirements per gram of EM as shown in Table 4. The calculated feed intake required for an average egg weight of 60 g and at egg production rates of 90 and 95% are based on the assumptions presented as a footnote (*) underneath this Table.

	Feed intake (g/d)		Egg mass (g/d)		SID-THR (mg/d)		Dietary SID-THR (%)		SID-THR:SID-LYS ratio**	
	Egg production rate (%)									
BW (kg)	90	95	90	95	90	95	90	95	90	95
1.5	112	115	54	57	524	553	0.469	0.482	72	70
1.6	114	117	54	57	524	553	0.458	0.471	72	70
1.7	117	120	54	57	524	553	0.447	0.460	72	70
1.8	120	123	54	57	524	553	0.437	0.450	72	70
1.9	122	125	54	57	524	553	0.428	0.441	72	70
2.0	125	128	54	57	524	553	0.419	0.432	72	70

*Feed intake is calculated based on: a feed with a MElh content of 11.8 MJ/kg, a requirement of 12.1 kJ per g egg mass, a maintenance requirement of 435 kJ ME per kg MBW (BW^0.75), a requirement of 21.5 kJ ME per gram BWG, a daily BWG of 1.5 g, and 9.5 kJ ME per kg BW per unit decrease in ºC below 25 ºC and a daily temperature of 22 ºC.

**The optimal SID-THR:SID-LYS ratio for maximum EM is calculated based on the ratio between SID-THR intake (SID-THR requirements calculated as 9.7 mg per gram of EM produced) and SID-LYS intake which is based on formula [F8] described in CVB documentation report nr. 69.

Table 6. Optimal SID-THR requirements for maximum EM expressed in mg/d and as a percentage of the diet for maximum EM at various egg production rates based on SID-THR requirements of 9.2 mg per gram of EM produced corresponding with the estimated SID-THR requirements per gram of EM as shown in Table 3. The calculated feed intake required for an average egg weight of 60 g and at egg production rates of 90 and 95% are based on the assumptions presented as a footnote (*) underneath this Table.

	Feed intake (g/d)		Egg mass (g/d)		SID-THR (mg/d)		Dietary SID-THR (%)		SID-THR:SID-LYS ratio**	
	Egg production rate (%)									
BW (kg)	90	95	90	95	90	95	90	95	90	95
1.5	112	115	54	57	497	524	0.445	0.457	68	66
1.6	114	117	54	57	497	524	0.434	0.446	69	66
1.7	117	120	54	57	497	524	0.424	0.436	68	66
1.8	120	123	54	57	497	524	0.415	0.427	69	66
1.9	122	125	54	57	497	524	0.406	0.418	68	66
2.0	125	128	54	57	497	524	0.398	0.410	69	66

*Feed intake is calculated based on: a feed with a MElh content of 11.8 MJ/kg, a requirement of 12.1 kJ per g egg mass, a maintenance requirement of 435 kJ ME per kg MBW (BW^0.75), a requirement of 21.5 kJ ME per gram BWG, a daily BWG of 1.5 g, and 9.5 kJ ME per kg BW per unit decrease in ºC below 25 ºC and a daily temperature of 22 ºC.

**The optimal SID-THR:SID-LYS ratio for maximum EM is calculated based on the ratio between SID-THR intake (SID-THR requirements calculated as 9.2 mg per gram of EM produced) and SID-LYS intake which is based on formula [F8] described in CVB documentation report nr. 69.

Table 7. Optimal SID-THR requirements for minimum FCR expressed in mg/d and as a percentage of the diet for minimum FCR at various egg production rates. Requirements are based on the relationship between observed SID-THR at minimum observed FCR and the corresponding FCR as shown in Figure 2 by the solid line. The calculated feed intake required for an average egg weight of 60 g and at egg production rates of 90 and 95% are based on the assumptions presented as a footnote (*) underneath this Table.

	Feed intake (g/d)		Egg mass (g/d)		SID-THR (mg/d)		Dietary SID-THR (%)		SID-THR:SID-LYS ratio**	
	Egg production rate (%)									
BW (kg)	90	95	90	95	90	95	90	95	90	95
1.5	112	115	54	57	532	567	0.476	0.494	73	72
1.6	114	117	54	57	526	562	0.460	0.479	72	71
1.7	117	120	54	57	520	557	0.444	0.463	71	70
1.8	120	123	54	57	513	551	0.428	0.448	70	70
1.9	122	125	54	57	505	544	0.412	0.434	69	69
2.0	125	128	54	57	496	536	0.397	0.419	69	68

*Feed intake is calculated based on: a feed with a MElh content of 11.8 MJ/kg, a requirement of 12.1 kJ per g egg mass, a maintenance requirement of 435 kJ ME per kg MBW (BW^0.75), a requirement of 21.5 kJ ME per gram BWG, a daily BWG of 1.5 g, and 9.5 kJ ME per kg BW per unit decrease in ºC below 25 ºC and a daily temperature of 22 ºC.

**The optimal SID-THR:SID-LYS ratio for maximum EM is calculated based on the ratio between SID-THR intake (SID-THR requirements are based on the relationship between observed SID-THR at minimum observed FCR and the corresponding FCR as shown in Figure 2 by the solid line) and SID-LYS intake which is based on formula [F8] described in CVB documentation report nr. 69.

In general, for high producing laying hens a SID-THR:SID-LYS ratio of 70%, corresponding with an intake of 553 mg SID-THR per day and an EM production of 57 g/d seems sufficient for both maximum EM (Table 5) and minimum FCR (Table 7), after which no further substantial increases in EM may be expected (Figure 3).

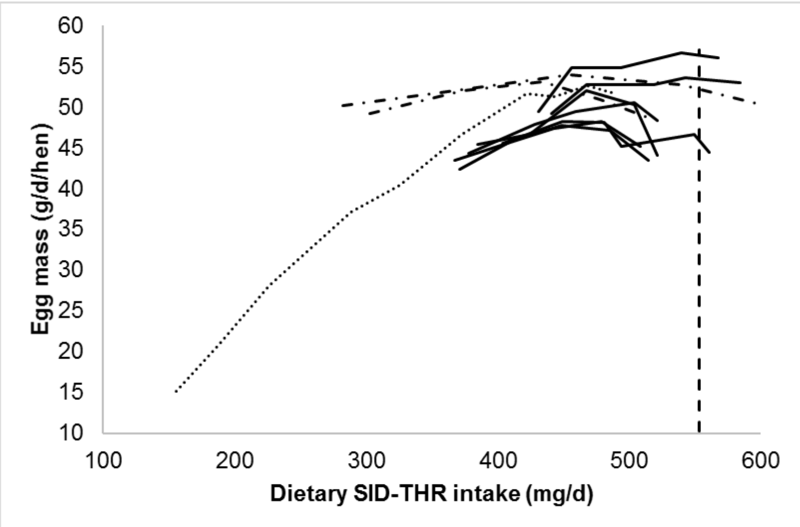


Figure 3. Relationship between dietary SID-THR intake (mg/d) and egg mass production (g/d/hen). The vertical dashed line has a dietary SID-THR value of 553 mg/d and is the estimated requirement for a bird producing an egg mass of 57 g/d. The two dash-dotted lines are the titration trials from the study of Ishibashi et al. (1997) (shortage of SID-TRP) and the dotted line is the study of Huyghebaert and Butler (1991) (dilution diet).

4 Conclusions

It is concluded that due to the sharp defined optimal dietary SID-THR concentration for maximum EM and minimum FCR (with reduced performance at lower and higher dietary SID-THR concentrations) it is wise to base SID-THR requirements on observed rather than estimated optimal SID-THR requirements. It is furthermore concluded that the SID-THR requirement for optimal performance is 9.7 mg SID-THR per gram of EM.

List of studies included in the meta-analysis

Cupertino, E. S., Gomes, P. C., Vargas Junior, J. G. d., Albino, L. F. T., Schmidt, M. & Mello, H. H. d. C. 2010. Níveis nutricionais de treonina digestível para poedeiras comerciais durante o segundo ciclo de postura. *Revista Brasileira de Zootecnia,* 39**,** 1993-1998.

da Rocha, T. C., Gomes, P. C., Donzele, J. L., Rostagno, H. S., de Carvalho Mello, H. H., Ribeiro, C. L. N. & Troni, A. R. 2013. Digestible threonine to lysine ratio in diets for laying hens aged 24-40 weeks. *Revista Brasileira de Zootecnia,* 42**,** 879-884.

Huyghebaert, G. & Butler, E. A. 1991. Optimum threonine requirement of laying hens. *British Poultry Science,* 32**,** 575-582.

Ishibashi, T., Ogawa, Y., Itoh, T., Fujimura, S., Koide, K. & Watanabe, R. 1998. Threonine Requirements of Laying Hens. *Poultry Science,* 77**,** 998-1002.

Sá, L. M., Gomes, P. C., Cecon, P. R., Rostagno, H. S. & D'Agostini, P. 2007. Nutritional requirement of digestible threonine for light-weight and semi-heavy laying hens in the period from 34 to 50 weeks old. *Revista Brasileira de Zootecnia,* 36**,** 1846-1853.

Schmidt, M., Gomes, P. C., Rostagno, H. S., Albino, L. F. T., Nunes, C. G. V. & Nunes, R. V. 2011. Nutritional levels of digestible threonine for white-egg laying hens in the second cycle of production. *Revista Brasileira de Zootecnia,* 40**,** 148-153.

Schmidt, M., Gomes, P. C., Rostagno, H. S., Albino, L. F. T., Nunes, R. V. & Cupertino, E. S. 2010. Nutritional requirement of digestible threonine to brown-egg laying hens on the 2nd cycle of production. *Revista Brasileira de Zootecnia,* 39**,** 1099-1104.

References

Blok, M. C. and R. A. Dekker. 2017. Table ‘Standardized ileal digestibility of amino acids in feedstuffs for poultry’. CVB Documentation report nr. 61.

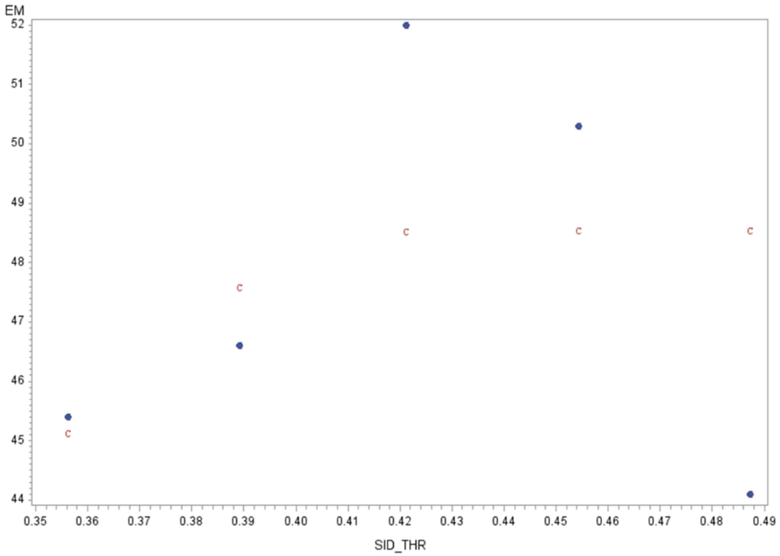
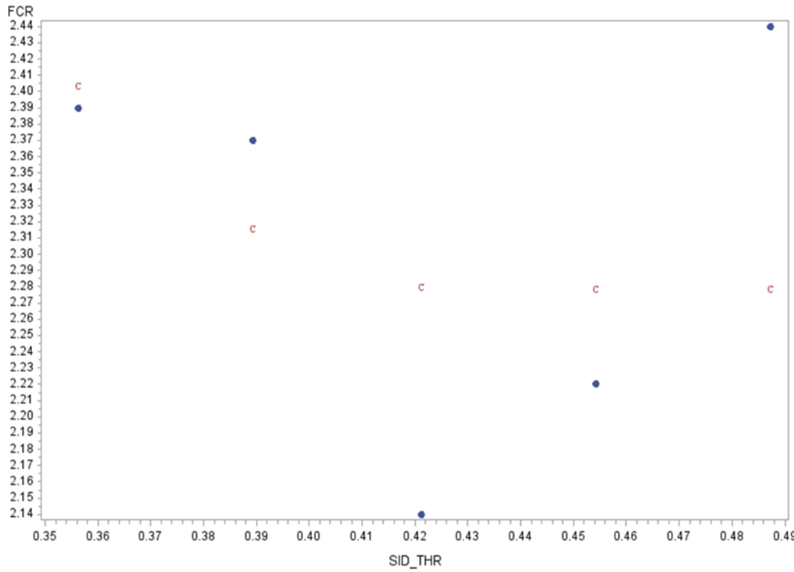
Krimpen, M. M., T. Veldkamp, J. W. van Riel, V. Khaksar, H. Hashemipour, M.C. Blok, and W. Spek. 2015. Estimating requirements for apparent faecal and standardised ileal digestible amino acids in laying hens by a meta-analysis approach.

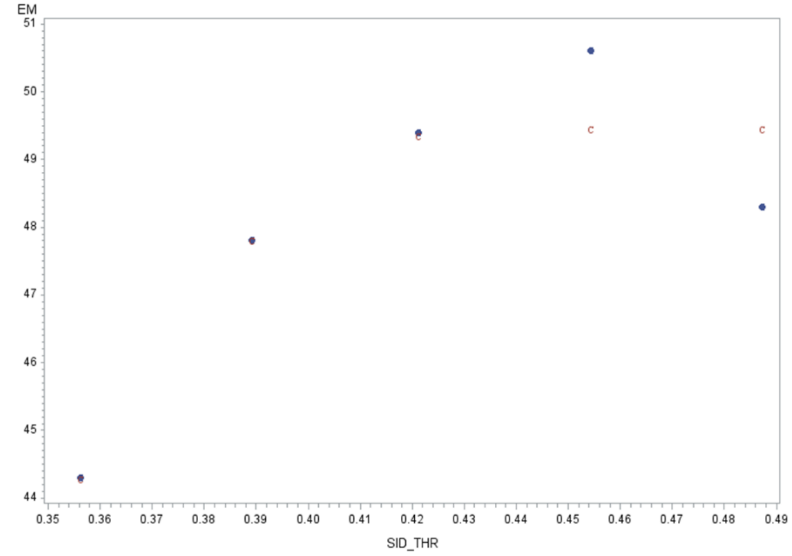
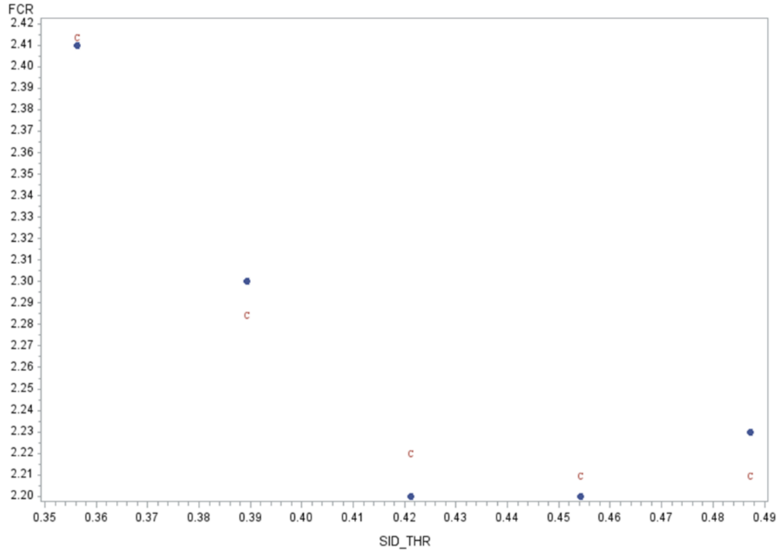
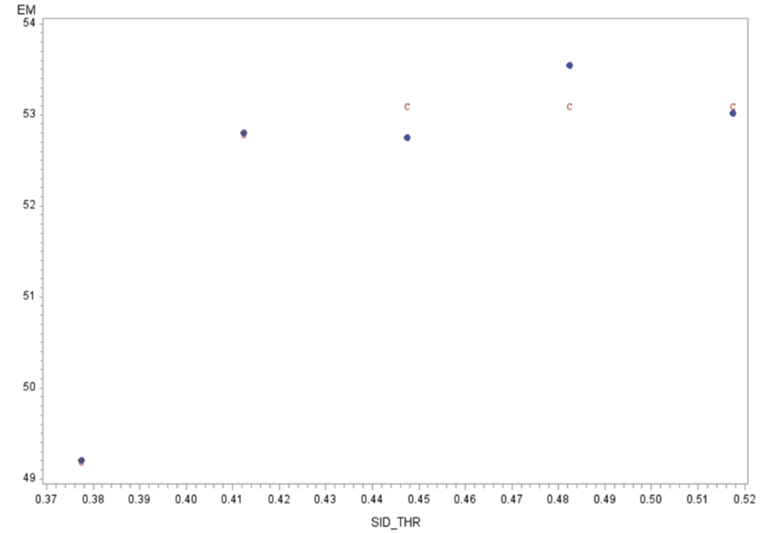
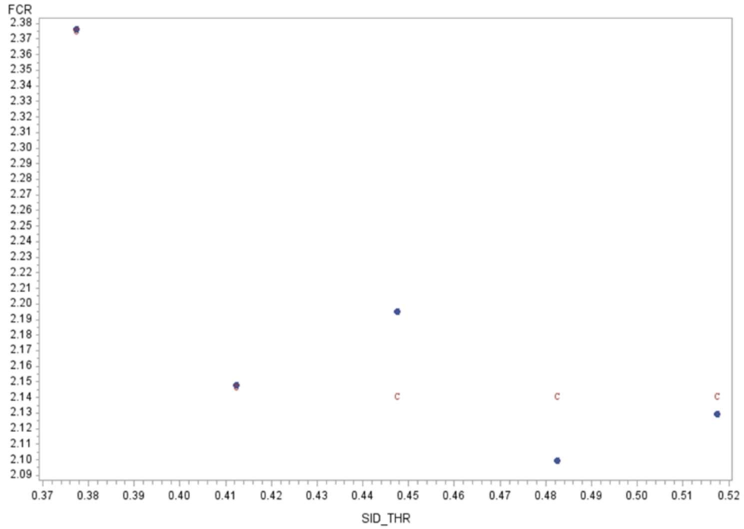
Robbins, K. R., Saxton, A. M. & Southern, L. L. 2006. Estimation of nutrient requirements using broken-line regression analysis. *Journal of Animal Science,* 84**,** E155-E165.

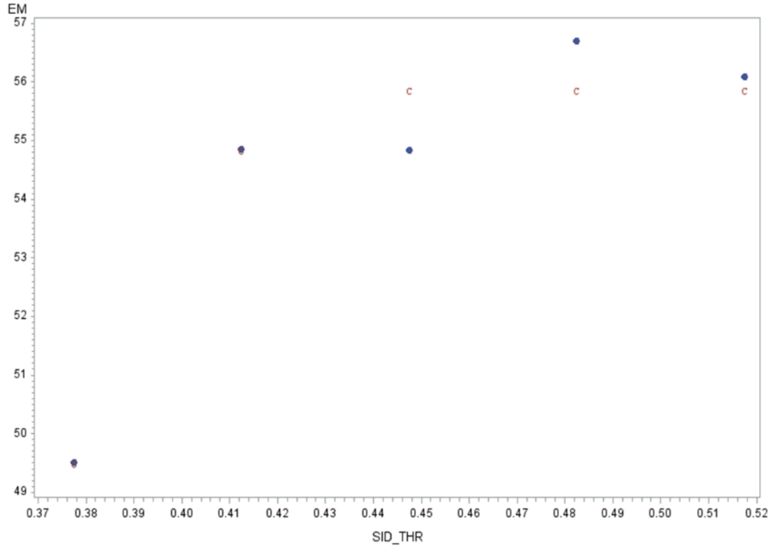
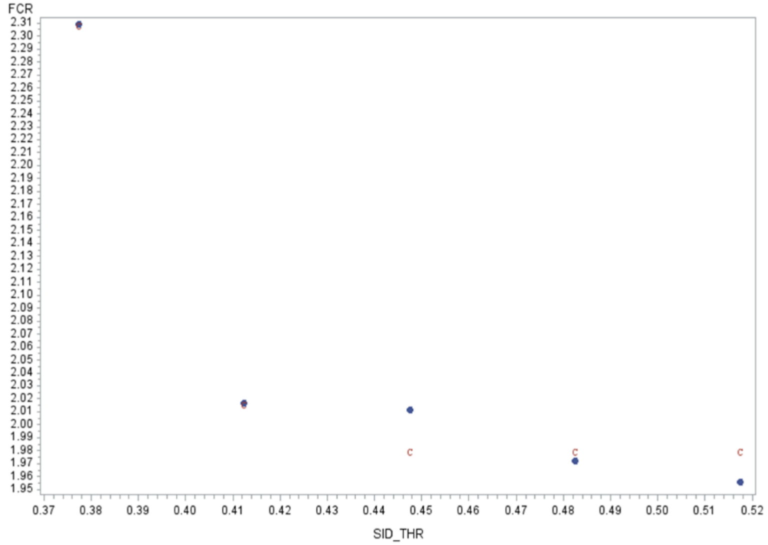
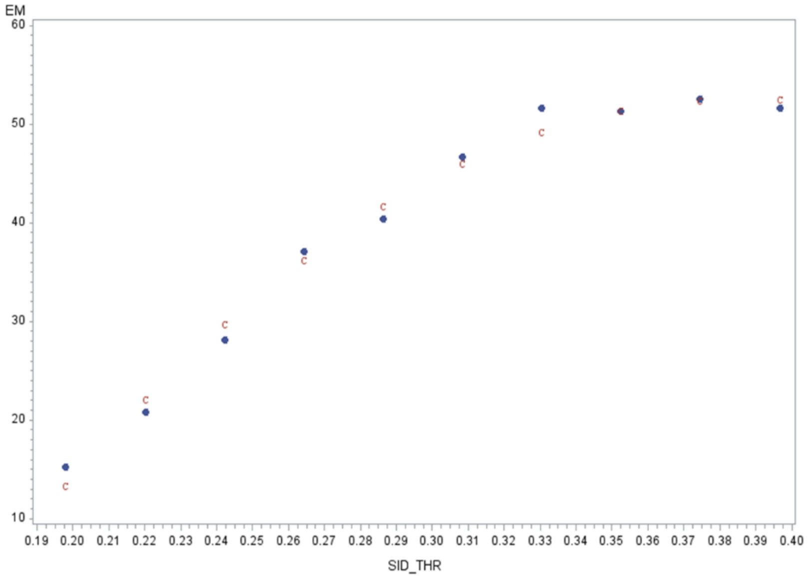
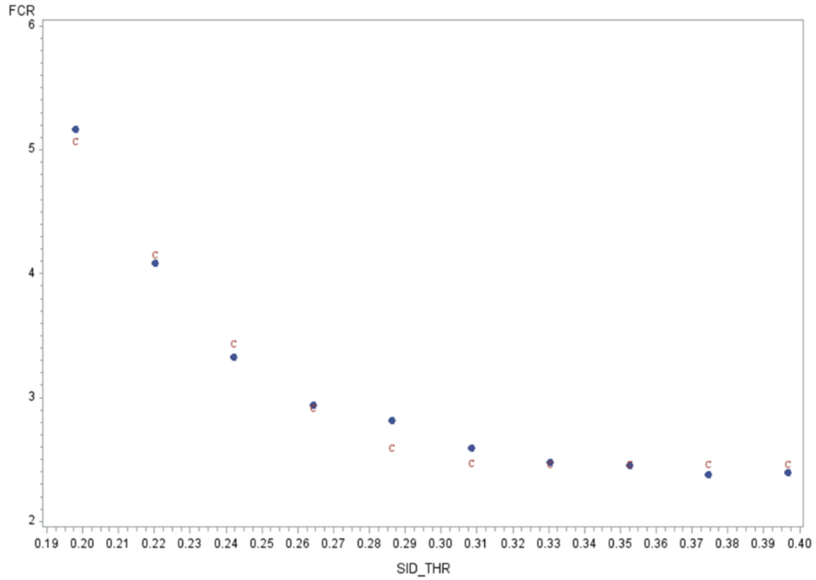
Spek, J. W. 2018. Standardized ileal digestible lysine requirement for laying hens. CVB Documentation report nr. 69.

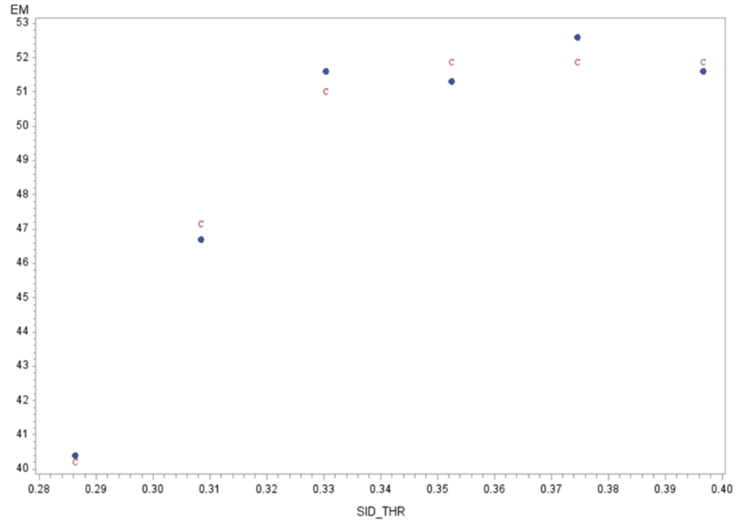
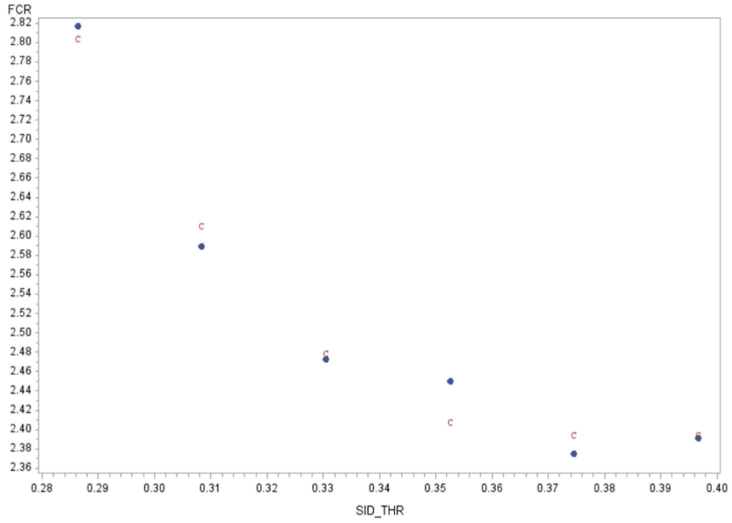
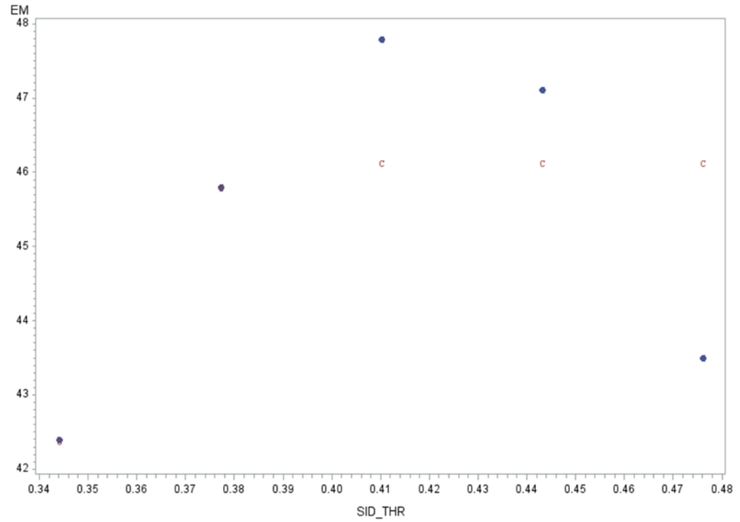
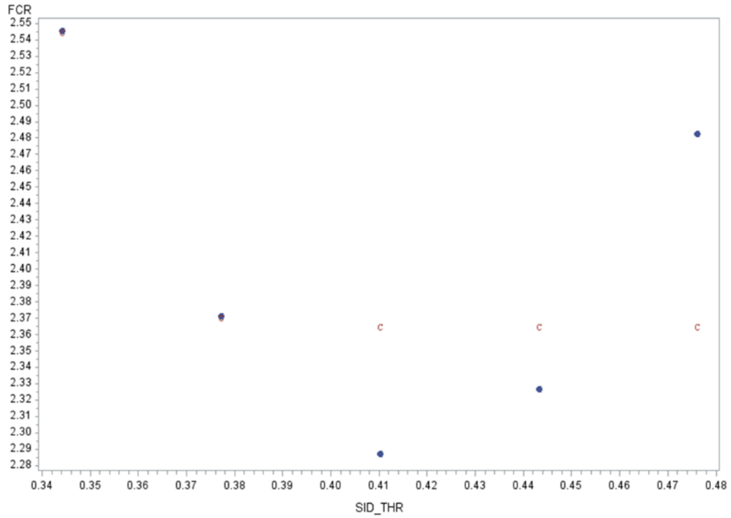
Appendix A. Relationship between dietary SID-THR supply and performance parameters FCR and EM for the various titration trials including the estimated SID-THR requirements based on the quadratic broken-line model

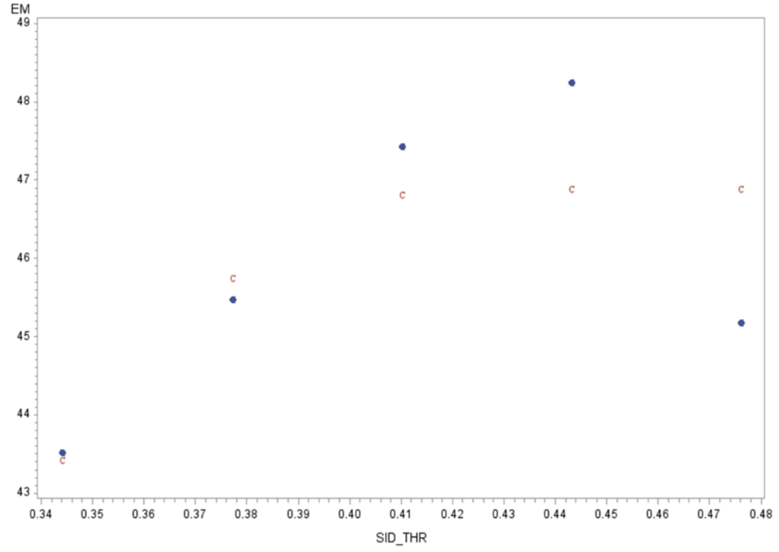
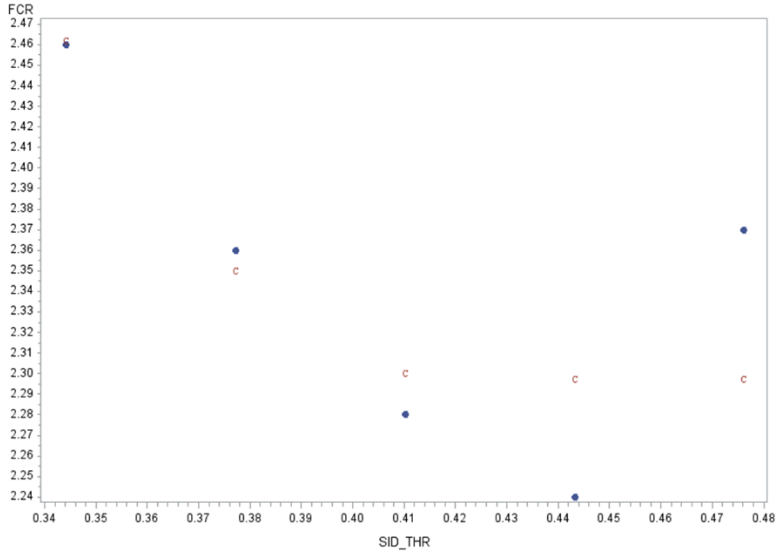
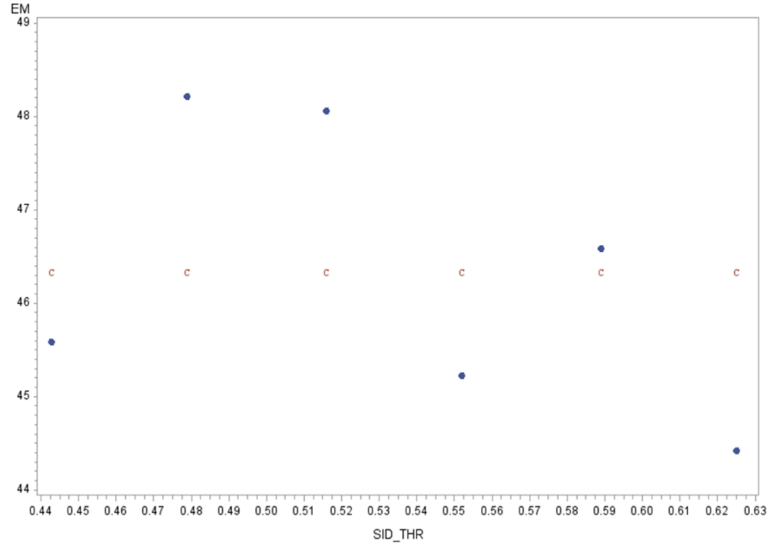
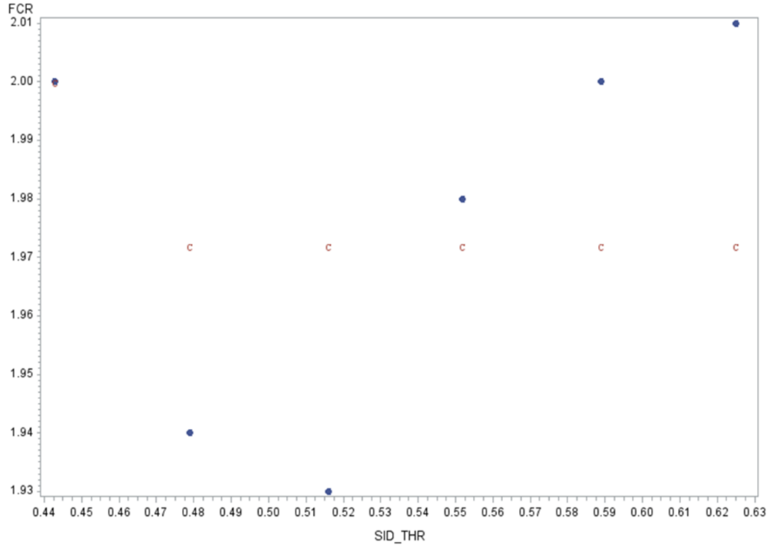
The letter ‘a’ behind the trial number (shown in the first column) means the model is fitted on all observations except the 4 observations with the lowest dietary SID-THR levels. If no letter is shown behind the trial number it means that the model is fitted based on all observations of the trial.

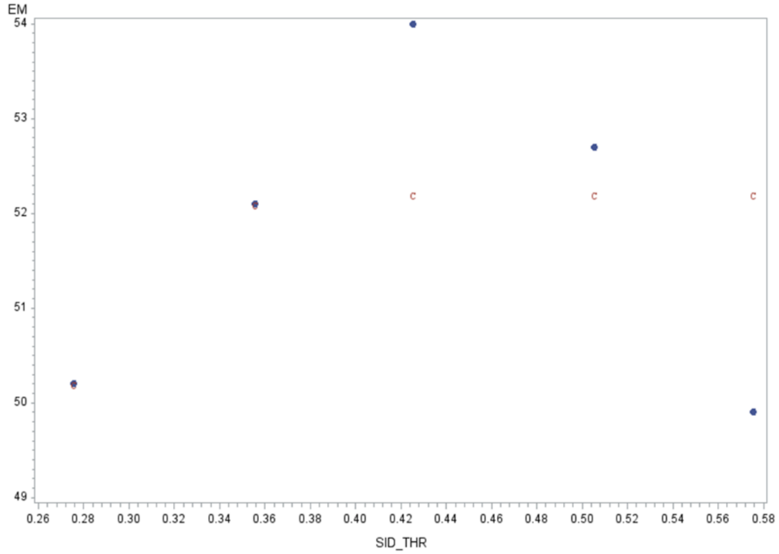
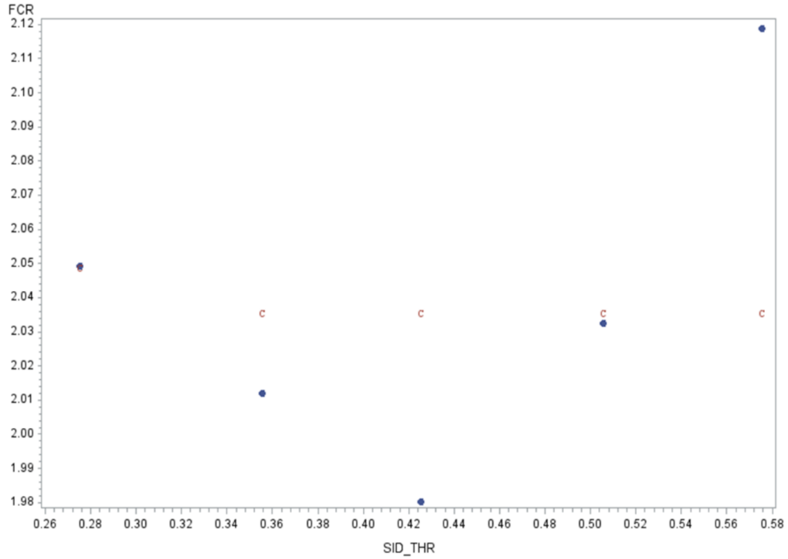
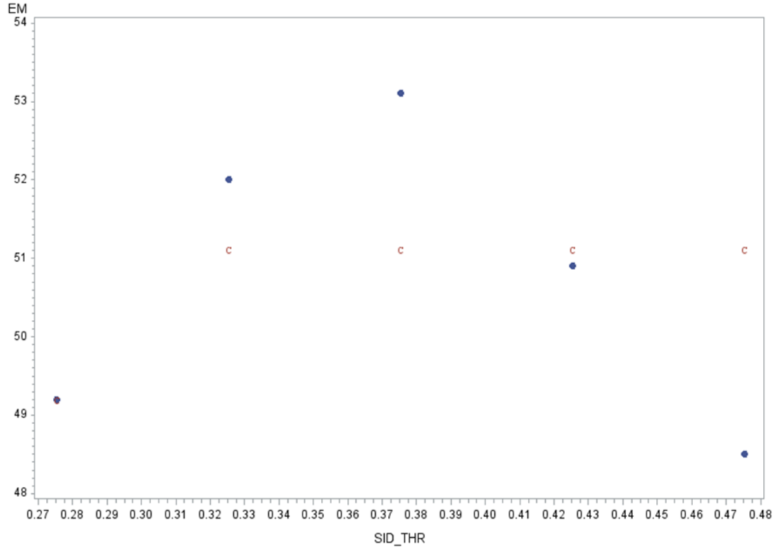
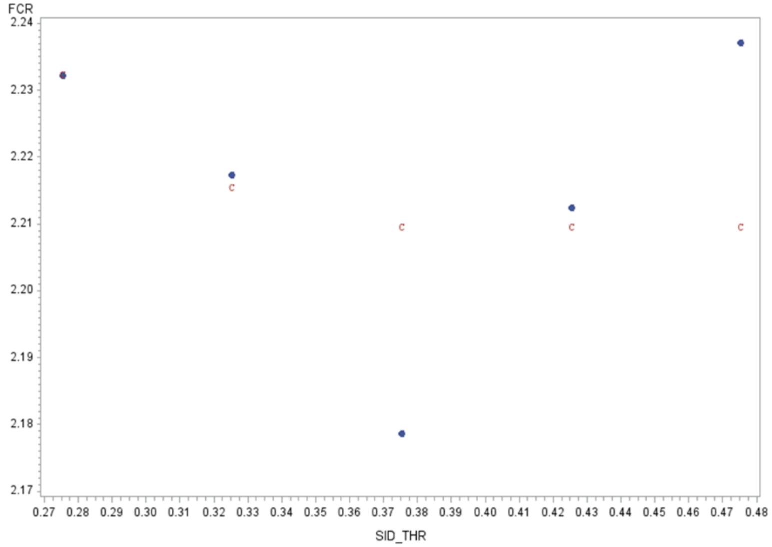
Study	Relationship between SID-THR (%) and EM (g/hen/day)	Relationship between SID-THR (%) and FCR (g feed/g EM)
1. Cupertino et al. (2010) Trial 1 SID-THR req. EM. (%) 0.427 SID-THR req. FCR. (%) 0.429		

2. Cupertino et al. (2010) Trial 2 SID-THR req. EM. (%) 0.432 SID-THR req. FCR. (%) 0.440		
3. Sá et al. (2007) Trial 1 SID-THR req. EM. (%) 0.426 SID-THR req. FCR. (%) 0.419		

4. Sá et al. (2007) Trial 2 SID-THR req. EM. (%) 0.436 SID-THR req. FCR. (%) 0.430		
5. Huyghebaert and Butler (1991) SID-THR req. EM. (%) 0.385 SID-THR req. FCR. (%) 0.312		

5a. Huyghebaert and Butler (1991) SID-THR req. EM. (%) 0.347 SID-THR req. FCR. (%) 0.367		
6. Schmidt et al. (2010) SID-THR req. EM. (%) 0.391 SID-THR req. FCR. (%) 0.384		

7. Schmidt et al. (2011) SID-THR req. EM. (%) 0.421 SID-THR req. FCR. (%) 0.420		
8. da Rocha et al. (2013) SID-THR req. EM. (%) Could not be estimated SID-THR req. FCR. (%) 0.445 No unique estimate possible		

9. Ishibashi et al. (1997) Trial 1 SID-THR req. EM. (%) 0.378 SID-THR req. FCR. (%) 0.355 No unique estimate possible		
10. Ishibashi et al. (1997) Trial 2 SID-THR req. EM. (%) 0.322 No unique estimate possible SID-THR req. FCR. (%) 0.377		

Appendix B. SID-THR model estimates for minimum FCR and maximum EM

SID-THR model estimates for minimum FCR. The letter ‘a’ behind the trial number (shown in the first column) means the model is fitted on all observations except the 4 observations with the lowest dietary SID-THR levels. If no letter is shown behind the trial number it means that the model is fitted based on all observations of the trial.

Trial nr.	Estimate L	Std. Err. L	Estimate R	Std. Err. R	Estimate U	Std. Err. U	R^2
1	2.28	0.103	0.429	0.2172	-24	143	0.183
2	2.21	0.016	0.440	0.0215	-29	15	0.964
3	2.14	0.028	0.419	0.0365	-134	227	0.900
4	1.98	0.017	0.430	0.0117	-119	53	0.980
5	2.48	0.055	0.312	0.0085	-202	33	0.986
5a	2.40	0.021	0.367	0.0121	-63	19	0.979
6	2.37	0.060	0.384	0.0902	-112	490	0.554
7	2.30	0.044	0.420	0.0714	-29	55	0.690
8	1.97	0.016	0.445	.	-5518	7694	0.114
9	2.04	0.030	0.355	.	-2	10	0.013
10	2.21	0.017	0.377	0.2963	-2	13	0.184

SID-THR model estimates for maximum EM. The letter ‘a’ behind the trial number (shown in the first column) means the model is fitted on all observations except the 4 observations with the lowest dietary SID-THR levels. If no letter is shown behind the trial number it means that the model is fitted based on all observations of the trial.

Trial nr.	Estimate L	Std. Err. L	Estimate R	Std. Err. R	Estimate U	Std. Err. U	R^2
1	49	2.6	0.427	0.2027	689	4025	0.196
2	49	0.8	0.432	0.0385	903	927	0.882
3	53	0.2	0.426	0.0141	1658	949	0.973
4	56	0.6	0.436	0.0204	1869	1317	0.944
5	53	1.1	0.385	0.0129	1127	154	0.99
5a	52	0.4	0.347	0.0074	3161	804	0.986
6	46	1.3	0.391	0.0784	1692	5573	0.504
7	47	1.1	0.421	0.0821	583	1256	0.632
8							
9	52	1.2	0.378	0.3549	188	1271	0.263
10	51	1.0	0.322	.	896	1024	0.203