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*Original study*

# Effect of varying supply of amino acids on nitrogen retention and growth performance of boars of different sire lines

Caroline Otten[1], Andreas Berk[1], Luise Hagemann[2], Simone Müller[3], Manfred Weber[4] and Sven Dänicke[1]

[1]Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, Braunschweig, [2]State Office for Rural Development, Agriculture and Land Reallocation Brandenburg, Teltow/Ruhlsdorf, [3]Thuringian State Institute for Agriculture, Regional Office Bad Salzungen, Bad Salzungen, [4]State Institute for Agriculture, Forestry and Horticulture Saxony-Anhalt, Centre for Livestock Husbandry and Equipment, Iden

## Abstract

Three diets with varying amino acid levels were fed in two nitrogen balance studies and two fattening experiments in order to determine the nitrogen retention and growth performance of boars of different sire lines. A total of 12 boars, 6 crossbreed boars sired by Piétrain boars (Study 1) and 6 crossbreed boars sired by Duroc boars (Study 2) were used in the nitrogen balance studies. The feeding trials with 214 boars (109 crossbreeds of Piétrain sire line 1×hybrid sow [Pi 1] and 105 crossbreeds Piétrain sire line 2×hybrid sow [Pi 2]) in Experiment 1 and 212 boars (106 Piétrain sire line 3×hybrid sow [Pi 3] and 106 Duroc×hybrid sow [Du]) in Experiment 2 were carried out in three performance test centres in parallel to the nitrogen balance studies.

Three diets with increasing content of amino acids were used; it was intended to use the same diets in nitrogen balance studies and the fattening experiments in order to compare the N retention and performance of boars during the growth period. The diets used in all experiments contained 13.4 MJ ME and 11.5 g lysine/kg (Diet 1), 13.2 g lysine/kg (Diet 2) and 14.9 g lysine/kg (Diet 3). The increase of the amino acid content of the diets seemed to have only a very minor impact on the nitrogen retention and on the growth performance of growing boars, whereas the location effect was found to be significant.

**Keywords:** amino acids, boars, nitrogen balance studies, lysine, fattening experiments

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**Corresponding author:**
Andreas Berk; email: andreas.berk@fli.bund.de
Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, 38116 Braunschweig, Germany

**Abbreviations:** AA: amino acid, BW: body weight, Du: Duroc hybrid sow, DWG: daily weight gain, FCR: feed conversion rate, ME: energy, N: nitrogen, Pi: Piétrain hybrid sow

## Introduction

Castration of male piglets without anaesthesia is traditionally practiced in many European countries to avoid boar taint. Meanwhile, castration without anaesthesia is known to produce pain and discomfort and will no longer be accepted by consumers and animal welfare organisations. Research has proven that this surgical procedure inflicts pain to piglets (Prunier *et al.* 2006). Apart from other possibilities, the fattening of non-castrated male pigs seems to be one of the most likely alternative solutions to surgical castration. Until today, it was common in Germany to use only gilts and barrows for fattening. Therefore, there are only incomplete recommendations for the feeding regimen of boars (DLG 2010). In general, boars have a superior growth performance and a higher lean meat percentage compared with barrows and/or gilts (Andersson *et al.* 1997). The higher anabolic potential of boars in comparison with castrated male pigs (barrows) was reported (Campbell & Taverner 1988, van Lunen & Cole 1996). Several authors stated that boars had a superior feed efficiency (Bonneau *et al.* 1994, van Lunen & Cole 1996) due to a simultaneous higher weight gain (Campbell & Taverner 1988) and lower feed consumption (Dunshea *et al.* 1993, Dunshea *et al.* 2001). Moreover, the carcasses of boars were leaner than those of barrows (Dunshea *et al.* 2001, Gispert *et al.* 2010, Boler *et al.* 2011).

In addition, it was determined that boars have a higher potential for protein deposition than gilts or barrows (Yen *et al.* 1986b, a) and therefore need more protein and amino acids (AAs) in their diet in order to perform maximum growth (Campbell *et al.* 1988). These findings result in different nutrition requirements of boars. Due to the shift from the fattening of barrows towards the fattening of boars, a scientific evidence basis on nutrition requirements of growing-finishing boars under typical German conditions is needed.

Within the joint research project »Feeding of boars« fundamentals of recommendations for boar nutrition should be established in cooperation with several research institutes and economic partners. Recommendations for the supply of growing-finishing boars with protein (amino acids) and energy (ME) should be derived from the results of several experiments. The aim of the present study was to determine the nitrogen (N) retention of boars under the influence of different AA levels and to verify this data in subsequent fattening experiments. The data serve to differentiate the demand for nutrients and energy supply of growing boars in general.

## Material and methods

### *Nitrogen balance studies*

A total of 12 boars were used in two N balance experiments. The studies were carried out at the Institute of Animal Nutrition, Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, Braunschweig, Germany. Treatments and experiments were in compliance with the European Union Guidelines concerning the protection of experimental animals and were approved by the Lower Saxony State Office for Consumer Protection and Food Safety (LAVES), Oldenburg, Germany (File Number 33.14-42502-04-078/09).

*Nitrogen balance Study 1*

Animals

In N Balance Study 1 six boars (Piétrain×commercial hybrid sow) with a mean start body weight (BW) of 43.6±2.2 kg (±standard deviation) were used.

Experimental diets

The three isoenergetic diets (13.40 MJ ME; Table 1) differed in their concentration of essential amino acids and generally based on the recommendation of the German Society of Nutrition Physiology for female pigs with a very high protein accretion based on the requirement of precaecal digestible AAs per day (GfE 2008). For calculation of the AA concentration of the diets the reference values of DLG (2010) for fattening of boars were taken into consideration. The dietary AA level of Diet 1 was slightly below these reference values and the AA level of Diet 2 and 3 were above these values.

The AAs were indicated as gross values instead of precaecal digestible AAs because only the gross values were determined analytically in this study.

Other AAs were added in relation to the first limiting AA lysine (lysine: methionine/cystine: threonine: tryptopane: valine=1:0.60:0.65:0.18:0.75). The experimental diets were fed as pellet feed.

Design and procedure

The experiment was conducted as a double 3×3 Latin square with six replicates per diet and consisted of three trial periods; each trial period was divided into an at least seven-day adaption period and an exactly seven-day collection period. During the adaption period the animals were kept in concrete floor boxes, each pig was fed twice daily. Before the collection period started, the boars were adapted to the balance cages for two days as described by Farries & Oslage (1961). The animals were housed in air-conditioned rooms. During the collection period the pigs were kept in single metal metabolism cages to enable the separate quantitative collection of urine and faeces. Urine was collected once and faeces twice daily. All the faeces produced in one collection period by one pig were stored at −18 °C. The daily feed amount was restricted to an amount consumed by all animals voluntarily. Pigs were fed at the level of 2.1 times the ME requirement for maintenance. The daily feed amount was given in two equal portions at 6.30 and 13.30. During the feeding times, the pigs had plenty of opportunity to take water according to their individual needs.

Sample preparation

At the end of the collection period the faeces were homogenised and representative samples were taken. The samples were freeze-dried and milled with a rotation lab mill through a 1 mm screen before being analysed. The urine was collected in bottles containing 20 ml of 5 % sulphuric acid to minimise atmospheric loss of N. Aliquot samples of acidified urine were pooled for each individual pig and were kept frozen. Before analysis, the urine was mixed, strained through super fine glass wool (Hecht Assistent, Sondheim, Germany) in order to remove possibly still present impurities. Representative samples of each diet were taken for feed analysis and milled through a 1 mm screen.

Table 1
Feed composition and analysis of N balance Studies 1 and 2

| Diet | 1 | 2 | 3 |
|---|---|---|---|
| Components, % Study 1 and 2 | | | |
| Wheat | 45.30 | 44.70 | 44.10 |
| Barley | 30.00 | 30.00 | 30.00 |
| Soy bean meal | 15.00 | 15.00 | 15.00 |
| Rapeseed meal | 4.50 | 4.50 | 4.50 |
| Soy bean oil | 2.00 | 2.00 | 2.00 |
| Mineral-Vitamin premix* | 1.43 | 1.52 | 1.60 |
| Minerals | 1.20 | 1.30 | 1.40 |
| Lysine-HCl | 0.34 | 0.51 | 0.68 |
| DL-Methionine | 0.09 | 0.19 | 0.30 |
| L-Threonine | 0.14 | 0.26 | 0.37 |
| L-Tryptophane | - | 0.02 | 0.05 |
| Calculated composition Study 1 and 2 | | | |
| ME, MJ/kg** | 13.40 | 13.40 | 13.40 |
| Lysine, g/kg | 11.50 | 13.20 | 14.90 |
| pcd Lysine, g/kg*** | 10.10 | 11.80 | 13.40 |
| Analysed composition, % Study 1 | | | |
| ME, MJ/kg** | 13.20 | 13.58 | 13.61 |
| Dry matter | 88.62 | 88.89 | 88.96 |
| Crude protein | 17.11 | 18.17 | 18.31 |
| Lysine, g/kg | 11.10 | 12.90 | 14.30 |
| Crude fat | 3.69 | 3.25 | 3.01 |
| Crude fiber | 4.16 | 3.15 | 3.50 |
| Crude ash | 4.81 | 5.07 | 4.71 |
| Analysed composition, % Study 2 | | | |
| ME, MJ/kg** | 12.73 | 13.26 | 13.21 |
| Dry matter | 88.44 | 88.30 | 88.58 |
| Crude protein | 18.42 | 17.80 | 18.87 |
| Lysine, g/kg | 10.70 | 12.40 | 13.70 |
| Crude fat | 3.77 | 3.25 | 3.29 |
| Crude fiber | 5.01 | 3.58 | 3.66 |
| Crude ash | 5.43 | 4.33 | 4.62 |

*Per kg grower diet (for diet 1 with 1.43 % premix): vitamin A ,10 000 IE; vitamin $D_3$, 1 250 IE; vitamin E 80 mg; vitamin $B_1$, 1.3 mg; vitamin $B_2$, 5.0 mg; vitamin $B_6$, 2.5 mg; vitamin $B_{12}$, 25 µg; vitamin $K_3$, 1.1 mg; nicotinic acid, 12.5 mg; calcium pantothenate, 5.0 mg; choline chloride, 125 mg; ferrous sulphate, 125 mg; copper sulphate, 15 mg; manganese (oxide), 80 mg; zinc (oxide), 100 mg; calcium iodate, 2 mg; sodium selenite, 0.40 mg; cobalt carbonate, 0.25 mg; phytase, 500 FTU, **Calculated on base of digestible (table values of the used compounds) crude nutrients (as analysed) according to , *** pcd Lysine means precaecally digestible lysine; calculated on base of table values

*Nitrogen balance Study 2*

Six boars (Duroc×commercial hybrid sow) with a mean start BW of 45.6±3.1 kg were used in N balance Study 2. Boars were fed at the level of 1.7 to 1.8 times the ME requirement for maintenance. The further experimental design and procedure was in accordance with the procedure of Study 1.

*Chemical analysis (Study 1 and 2)*

Collected samples of feed and faeces were analysed according the methods of VDLUFA (2007). Crude fat, crude fibre and crude ash were analysed according to Methods 5.1.1, 6.1.1 and 8.1, respectively. Crude protein in the diets and in the faeces was measured using the method of Dumas (Method number 4.1.2). Furthermore, the diets were analysed for sugar (according to Luff-Schoorl, Method 7.1.1) and starch (polarmetrically, Method 7.2.1). The AA content of the diets, with the exception of tryptophan, was analysed by ion exchange chromatography using an Amino Acid Analyser (Method number 4.11.1; Biochrom Ltd., Cambridge, UK). Tryptophan was determined by HPLC with fluorescence detection (Anonymous 2000). Urine was analysed for nitrogen content following the Kjeldhal method (Method number 4.1.1).

*Calculations and statistics (Study 1 and 2)*

The nitrogen retention was calculated as the diet N minus N in faeces and urine (in grams per day). For nitrogen utilisation (expressed as a percentage) the N retention was divided by the N intake. The digestibility was calculated with the (GfE 2005a) formula:

$$digestability, \% = \frac{intake - excretion}{intake} \times 100$$

where intake (g/d) is the dry matter (DM) intake (g/d)×content of the nutrient (g/kg DM) and excretion (g/d) is the DM amount excreted with the faeces (kg/d)×nutrient content in the faeces (g/kg DM).

The energy concentration of the diets was estimated using the prediction equation based on apparent digestible nutrients as proposed by the GfE (2008). For analysis of the nitrogen balances, the BWs of the animals were raised to the power of 0.67 in order to minimise the influence of individual BW on the results (Hoffmann & Gebhardt 1973). The experimental data were analysed by a repeated measures analysis using the PROC MIXED procedure of SAS 9.2 (SAS Institute Inc., Cary, NC, USA). The effects of period and diet and their interactions were included in the model. The least square means, their standard errors, levels of significance for main effects and the associated interaction were determined. *P*-values $<0.05$ were considered to be significant.

*Fattening experiments*

Animals

Two successive fattening experiments were conducted with a total of 228, respectively 229, boars at the beginning of the experiments. The pigs were produced specifically for the project and were progeny of four genetic different sire lines (Piétrain 1-3 and one Duroc). On experimental grounds, 14 pigs (Experiment 1), respectively 17 pigs (Experiment 2), had to be removed from the experiment, with the result that the experiment was finished by 214, respectively 212, boars.

### Experimental diets

The feed composition of the diets fed in Experiment 1 and 2 was consistent with the composition of the diets used in N Balance Study 1 and 2. The analyses of the diets of the fattening experiments showed only minimal deviations within the latitude compared to the analysis results of the N balance diets. Therefore the analysis result of N Balance Study 1 was equated with the analysis results of Fattening Experiment 1 and for N Balance Study 2 with Experiment 2 (Table 1).

### Design and procedure

In Experiment 1 and 2 the total number of animals was randomly divided within the full- and half-sibling groups over three pig performance test centres in Germany: Location 1, 2 and 3. N balance Study 1 and Fattening Experiment 1 used full- and half-sibling boars of the same sire lines and N Balance Study 2 and Fattening Experiment 2 also. The pigs were randomly allotted to three diets in consideration of their genetic relationships.

Pigs were housed in climate controlled buildings (on average 13 pigs per pen (Location 1 and 2), respectively 12 pigs per pen (Location 3) and 1.0 $m^2$ (per pig) with partly slatted floor (Location 1 and 2) or fully slatted concrete floor (Location 3). Pelleted feed and water were offered for consumption on *ad libitum* basis. Every performance test centre had demanded feeding stations with a single animal detection via transponder (FIRE-stations (Osborne) in Location 1 and INSENTEC-stations in Location 2 and 3).

The overall experimental period lasted from an average BW of 30 kg until the time of slaughter up to a BW of aspired 120 kg. The feeding regimen was a two phase feeding, with a per pen change from grower to finisher feed at approximately 70 kg BW. To enhance comparability with the N balance studies, only the performance data from the grower phase (30-70 kg BW) were considered in this study.

### Sample preparation and analysis

Samples of each diet were collected and analysed for dry matter, crude nutrients and amino acids according to the methods described in detail above.

### Calculations and statistics

The experimental data was analysed using the PROC MIXED procedure of SAS 9.2 (SAS Institute Inc., Cary, NC, USA). The effects of the performance test centre (location), diet and sire line and their interactions were included in the model as fixed factors and the biological father was used as a random factor. Based on data from pig individual performance the statistics were built. The least square means, their standard errors, levels of significance for main effects and the associated interaction were determined. $P$-values <0.05 were considered to be significant.

Daily weight gain (DWG) was calculated as the difference between BW at the end of the growth period minus start weight divided by days of the experimental period. Feed intake was measured daily by the respective feeding station. The energy intake was calculated using the feed intake data and the ME level of the respective diet. The feed conversion rate

(FCR) was obtained as feed intake divided by gain. Moreover pooled least square means of the three fixed factors were calculated for each experimental run.

## Results

### *Nitrogen balance studies*

The effects of period and diet on N retention, N utilisation and digestibility of crude nutrients of the boars used in N Balance Study 1 and 2 are presented in Table 2. In Period 1 of Study 2, one boar of Feeding Group 3 had to be excluded from the trial for health reason.

In Study 1 there was no significant effect on N retention of the boars, neither for period nor for diet. In Study 2, there was a significant increased N retention for the pigs received Diet 2 or 3 compared to those consumed Diet 1 ($P$<0.01). Likewise, the N utilisation increased ($P$<0.05). The crude protein digestibility of the pigs also increased ($P$<0.05) parallel to the increasing BW and age (period) and AA content of the diet in Studies 1 and 2. This result also applies to the digestibility of crude fat in Study 2. Organic matter and N-free extract digestibility was higher ($P$<0.01) in pigs that received Diet 2 or 3 than in pigs received Diet 1 in Study 1. However, the digestibility of N-free extracts was higher ($P$<0.05) for pigs that received Diet 1 than pigs fed with Diet 3. In none of the studies could significant interactions be observed between period×diet.

Table 2
N retention and nutrient digestibility in N balance Studies 1 and 2 (least square means and pooled standard error of means)

| N Balance Study 1 | Period | | | Diet | | | PSEM | ANOVA (*P*-value)* | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | | Period | Diet |
| N-Ret, g/kg BW$^{0.67}$ | 1.87 | 1.89 | 1.81 | 1.78 | 1.93 | 1.85 | 0.02 | 0.305 | 0.067 |
| N-Ret, g/d | 24.32$^{c}$ | 27.96$^{b}$ | 30.78$^{a}$ | 26.71 | 28.70 | 27.65 | 0.38 | <0.001 | 0.163 |
| N-Utilisation, % | 60.75 | 61.08 | 58.76 | 60.35 | 61.32 | 58.91 | 1.46 | 0.326 | 0.347 |
| dXP, % | 83.74$^{b}$ | 86.11$^{a}$ | 88.04$^{a}$ | 84.14$^{b}$ | 87.14$^{a}$ | 86.61$^{ab}$ | 0.31 | <0.01 | 0.025 |
| dOM, % | 86.90 | 87.54 | 88.05 | 85.65$^{b}$ | 88.36$^{a}$ | 88.48$^{a}$ | 0.30 | 0.238 | <0.01 |
| dXL, % | 71.06 | 71.36 | 69.82 | 70.98 | 71.20 | 70.06 | 1.36 | 0.752 | 0.854 |
| dXF, % | 33.77 | 36.09 | 38.27 | 32.61 | 34.29 | 41.23 | 2.42 | 0.388 | 0.062 |
| dXX, % | 91.99 | 92.00 | 92.11 | 90.76$^{b}$ | 92.55$^{a}$ | 92.78$^{a}$ | 0.19 | 0.936 | 0.003 |
| **N Balance Study 2** | **Period** | | | **Diet** | | | **PSEM** | **ANOVA (*P*-value)*** | |
| | 1 | 2 | 3 | 1 | 2 | 3 | | Period | Diet |
| N-Ret, g/kg BW$^{0.67}$ | 1.61 | 1.62 | 1.67 | 1.52$^{b}$ | 1.66$^{a}$ | 1.72$^{a}$ | 0.14 | 0.360 | <0.01 |
| N-Ret, g/d | 21.05$^{b}$ | 23.93$^{b}$ | 28.24$^{a}$ | 22.38$^{b}$ | 24.72$^{ab}$ | 26.11$^{a}$ | 1.27 | <0.01 | 0.028 |
| N-Utilisation, % | 59.62 | 58.25 | 60.09 | 54.21$^{b}$ | 61.79$^{a}$ | 61.96$^{a}$ | 4.56 | 0.638 | 0.016 |
| dXP, % | 82.66$^{b}$ | 84.78$^{ab}$ | 87.34$^{a}$ | 82.39$^{b}$ | 86.38$^{a}$ | 86.01$^{a}$ | 1.34 | 0.016 | 0.015 |
| dOM, % | 84.44 | 85.48 | 86.92 | 83.69 | 86.79 | 86.36 | 0.87 | 0.136 | 0.055 |
| dXL, % | 66.42$^{b}$ | 69.55$^{ab}$ | 71.84$^{a}$ | 71.03$^{a}$ | 69.51$^{ab}$ | 67.28$^{b}$ | 1.81 | <0.01 | 0.037 |
| dXF, % | 25.58 | 30.99 | 36.52 | 33.67 | 30.74 | 28.69 | 3.93 | 0.057 | 0.340 |
| dXX, % | 90.01 | 90.42 | 91.22 | 89.43 | 91.24 | 90.98 | 0.72 | 0.216 | 0.060 |

*period*diet were non-significant ($P$<0.05), Values with different superscripts differ significantly ($P$<0.05), N-Ret (g/kg LWG): N retention (g/kg live weight gain), dXP: digestibility of crude protein, dOM: digestibility of organic matter, dXL: digestibility of crude lipid, dXF: digestibility of crude fiber, dXX: digestibility of nitrogen free extractives

*Fattening experiments*

The data from the growth period (30 kg until approximately 70 kg BW) of Fattening Experiment 1 and 2 were presented in Tables 3 and 4. As the N balance experiments are performed during the growth period, only the corresponding growth performance results of the fattening experiments are presented here. Therefore, data from the subsequent finishing period will not be considered in detail. In general, the boars of all used sire lines were characterised by a high performance level over the complete fattening period (30 kg until approximately 120 kg) in both experiments with average daily weight gains between 921 g/d and 1 149 g/d (data not shown).

Experiment 1

Dietary treatment or sire line did not affect growth performance or feed intake of the boars in Experiment 1 (Table 3). The location, which implies the housing conditions, was identified to be the major factor influencing performance. Average DWG was similar for boars kept at Locations 1 and 2 (937 g/d respectively 929 g/d) but for pigs kept at Location 3 this parameter was significantly reduced to 867 g/d ($P$<0.001). Pigs reared in Location 1 showed a significantly higher daily feed intake (1.82 kg/d (Location 1) vs. 1.74 kg/d (Location 3)) and therefore also a higher energy intake (24.52 MJ/d (Location 1) vs. 23.44 MJ/d (Location 3)) on average than the pigs housed in Location 3. Moreover, the pigs housed in Location 3 had an about 4 % improved mean FCR compared to pigs of Location 1 and 2. There was a location×diet interaction ($P$<0.05), a location×sire line interaction ($P$<0.05) and a diet×sire line interaction ($P$<0.05) observed for FCR.

Experiment 2

The location was the main influence factor on performance and feed intake of the boars used in Experiment 2 (Table 4). It is conspicuous that pigs reared in Location 2 showed significant lower average DWG ($P$<0.001) of 838 g/d compared to pigs of Location 1 (980 g/d) or Location 3 (1 003 g/d). This observation continues with all other measured parameters, where the pigs housed in Location 2 showed less average performance values ($P$<0.001) than pigs raised in Location 1 or 3. However, boars received the experimental Diet 1 exhibited significantly increased DWG (974 g/d compared to 934 g/d (Diet 2) or 913 g/d (Diet 3)) on average for the whole experimental run. In addition the type of sire line influenced the amount of DWG ($P$<0.001). Crossbreeds of Du sired pigs showed an approximately 9 % higher DWG than Pi 3 crossbreeds. The FCR of Pi 3 crossbreeds were reduced by 9 % on average as well. There were significant interactions detected between location×diet, location×sire line and location×diet×sire line for DWG. The same interactions were observed for FCR.

## Discussion

The present experiments aimed at examining the N retention of boars under the influence of different AA levels and detecting the optimum AA level for maximum growth rate and feed efficiency by mean of feeding trials. In Table 2 the N retention was mentioned in (g/d) and in (g/kg $BW^{0.67}$). The N retention in grams per day was significantly affected by the period

Table 3
Performance and feed intake least square means and pooled standard error of means in Fattening Experiment 1 (growth period)

| Location | Diet | Sire line | n | DWG, g | Feed intake, kg/d | ME intake, MJ ME/d | FCR, kg/kg |
|---|---|---|---|---|---|---|---|
| 1 | 1 | Pi 1 | 13 | 913 | 1.84 | 24.30 | 2.01 |
| 1 | 1 | Pi 2 | 11 | 941 | 1.86 | 24.59 | 1.97 |
| 1 | 2 | Pi 1 | 11 | 919 | 1.81 | 24.54 | 1.97 |
| 1 | 2 | Pi 2 | 12 | 950 | 1.84 | 24.99 | 1.94 |
| 1 | 3 | Pi 1 | 13 | 945 | 1.80 | 24.45 | 1.90 |
| 1 | 3 | Pi 2 | 12 | 952 | 1.78 | 24.27 | 1.88 |
| 2 | 1 | Pi 1 | 12 | 917 | 1.86 | 24.49 | 2.02 |
| 2 | 1 | Pi 2 | 13 | 913 | 1.81 | 23.86 | 1.98 |
| 2 | 2 | Pi 1 | 13 | 960 | 1.79 | 24.24 | 1.86 |
| 2 | 2 | Pi 2 | 11 | 903 | 1.72 | 23.42 | 1.91 |
| 2 | 3 | Pi 1 | 13 | 957 | 1.81 | 24.58 | 1.89 |
| 2 | 3 | Pi 2 | 11 | 923 | 1.81 | 24.70 | 1.96 |
| 3 | 1 | Pi 1 | 12 | 873 | 1.73 | 22.84 | 1.98 |
| 3 | 1 | Pi 2 | 12 | 874 | 1.72 | 22.65 | 1.97 |
| 3 | 2 | Pi 1 | 12 | 905 | 1.75 | 23.74 | 1.94 |
| 3 | 2 | Pi 2 | 12 | 845 | 1.75 | 23.73 | 2.01 |
| 3 | 3 | Pi 1 | 10 | 899 | 1.74 | 23.70 | 1.94 |
| 3 | 3 | Pi 2 | 11 | 804 | 1.76 | 23.96 | 2.23 |
| Pooled LSM | | | | | | | |
| Location | | | | | | | |
| 1 | | | 72 | 937 | 1.82 | 24.52 | 1.94 |
| 2 | | | 73 | 929 | 1.80 | 24.21 | 1.94 |
| 3 | | | 69 | 867 | 1.74 | 23.44 | 2.01 |
| | Diet | | | | | | |
| | 1 | | 73 | 905 | 1.80 | 23.79 | 1.99 |
| | 2 | | 71 | 914 | 1.78 | 24.11 | 1.94 |
| | 3 | | 70 | 913 | 1.78 | 24.27 | 1.97 |
| | | Sire line | | | | | |
| | | Pi 1 | 109 | 921 | 1.79 | 24.10 | 1.94 |
| | | Pi 2 | 105 | 900 | 1.78 | 24.02 | 1.98 |
| Pooled SEM | | | 28.1 | 0.05 | 0.73 | 0.05 | |
| ANOVA (*P*-value) | | | | | | | |
| location | | | | <0.001 | 0.033 | 0.034 | 0.015 |
| diet | | | | 0.825 | 0.645 | 0.443 | 0.166 |
| sire line | | | | 0.304 | 0.876 | 0.878 | 0.107 |
| location×diet | | | 0.711 | 0.477 | 0.487 | 0.008 | |
| location×sire line | | | | 0.069 | 0.705 | 0.708 | 0.031 |
| diet×sire line | | | 0.252 | 0.949 | 0.949 | 0.024 | |
| location×diet×sire line | | | 0.784 | 0.940 | 0.938 | 0.275 | |

Values with $P<0.05$ were considered to be significant, DWG: daily weight gain; FCR: feed conversion ratio

Table 4
Performance and feed intake (least square means and pooled standard error of means) in Fattening Experiment 2 (growth period)

| Location | Diet | Sire line | n | DWG, g | Feed intake, kg/d | ME intake, MJ ME/d | FCR , kg/kg |
|---|---|---|---|---|---|---|---|
| 1 | 1 | Pi 3 | 12 | 899 | 1.85 | 23.52 | 2.06 |
| 1 | 1 | Du | 16 | 1 048 | 1.92 | 24.37 | 1.83 |
| 1 | 2 | Pi 3 | 11 | 967 | 1.80 | 23.89 | 1.86 |
| 1 | 2 | Du | 13 | 986 | 1.87 | 24.80 | 1.89 |
| 1 | 3 | Pi 3 | 12 | 904 | 1.77 | 23.33 | 1.96 |
| 1 | 3 | Du | 11 | 1 076 | 1.85 | 24.45 | 1.71 |
| 2 | 1 | Pi 3 | 12 | 961 | 1.81 | 23.03 | 1.88 |
| 2 | 1 | Du | 12 | 996 | 1.76 | 22.43 | 1.77 |
| 2 | 2 | Pi 3 | 13 | 774 | 1.67 | 22.13 | 2.17 |
| 2 | 2 | Du | 11 | 860 | 1.62 | 21.51 | 1.89 |
| 2 | 3 | Pi 3 | 12 | 760 | 1.69 | 22.31 | 2.23 |
| 2 | 3 | Du | 10 | 677 | 1.54 | 20.41 | 2.36 |
| 3 | 1 | Pi 3 | 11 | 887 | 1.79 | 22.77 | 2.03 |
| 3 | 1 | Du | 10 | 1 054 | 1.87 | 23.76 | 1.78 |
| 3 | 2 | Pi 3 | 11 | 936 | 1.85 | 24.56 | 1.99 |
| 3 | 2 | Du | 12 | 1 077 | 1.82 | 24.19 | 1.70 |
| 3 | 3 | Pi 3 | 12 | 994 | 1.96 | 25.86 | 1.97 |
| 3 | 3 | Du | 11 | 1 067 | 1.83 | 24.23 | 1.73 |
| Pooled LSM | | | | | | | |
| Location | | | | | | | |
| 1 | | | 75 | 980 | 1.84 | 24.06 | 1.89 |
| 2 | | | 70 | 838 | 1.68 | 21.97 | 2.05 |
| 3 | | | 67 | 1 003 | 1.85 | 24.23 | 1.87 |
| | Diet | | | | | | |
| | 1 | | 73 | 974 | 1.83 | 23.32 | 1.89 |
| | 2 | | 71 | 934 | 1.77 | 23.51 | 1.92 |
| | 3 | | 68 | 913 | 1.77 | 23.43 | 1.99 |
| | | Sire line | | | | | |
| | | Pi 3 | 106 | 898 | 1.80 | 23.49 | 2.02 |
| | | Du | 106 | 983 | 1.79 | 23.35 | 1.85 |
| Pooled SEM | | | | 30.3 | 0.06 | 0.81 | 0.05 |
| ANOVA (*P*-value) | | | | | | | |
| location | | | | <0.001 | <0.001 | <0.001 | <0.001 |
| diet | | | | 0.001 | 0.123 | 0.898 | 0.002 |
| sire line | | | | <0.001 | 0.832 | 0.823 | <0.001 |
| location×diet | | | | <0.001 | 0.074 | 0.064 | <0.001 |
| location×sire line | | | | 0.001 | 0.072 | 0.072 | 0.012 |
| diet×sire line | | | | 0.168 | 0.362 | 0.368 | 0.368 |
| location×diet×sire line | | | | 0.003 | 0.735 | 0.733 | <0.001 |

Values with $P<0.05$ were considered to be significant, DWG: daily weight gain, FCR: feed conversion ratio (depending on BW and feed intake) in both studies. For the reason mentioned above, the period effect was eliminated by using the N retention in the unit of (g/kg $BW^{0.67}$). Therefore, the results were discussed in the unit of N retention (g/kg $BW^{0.67}$) in the following.

In contrast to recent suggestions, the diet composition (the dietary AA content, in this case) seemed to have only a very minor impact on N retention and performance in the current investigations. Moreover, the experimental diet exhibited no significant effect on the N retention of the Piétrain sired boars used in Study 1, whereas the Duroc sired boars used in Study 2 showed a significantly increased N retention for pigs received Diet 2 or 3 compared to those that consumed Diet 1. Several authors mentioned higher N retention for pigs fed diets with increased AA concentrations (5.0 g lysine/kg and 11.0 g lysine/kg) in the diets, respectively several diets, with increasing AA levels (8.1 till 13.1 g lysine/kg) during the growth period (Fabian *et al.* 2004, O'Connell *et al.* 2006). Reynolds & O'Doherty (2006) also described that the pigs fed a high lysine level (12.5 g/kg) had a higher ($P<0.05$) N retention than pigs fed diets with lower lysine concentrations (10.5 till 8.5 g lysine/kg). These findings support the presumption that the chosen range of lysine levels in the current study did not induce significant differences in N retention of boars from all tested sire lines.

Acciaioli *et al.* (2011) described significant differences in N retention and utilisation between pigs of different breeds. It seems that one reason for the lack of comparability of the results of the current two N balance studies might be the use of boars with different genetic backgrounds.

In the present study it is not clearly defined whether a high or low lysine level is relevant for an improved N utilisation, the N utilisation fluctuated around 60 %. Other authors observed also increasing and decreasing N utilisations (O'Connell *et al.* 2006, Reynolds & O'Doherty 2006). In general, the reported N utilisations of the present studies (approximately 60 %) were in good accordance with the findings of Lenis *et al.* (1999) and Markert *et al.* (1993).

Many factors are known to influence apparent digestibility of nutrients, for instance characteristics of the feed or animal factors like BW or genotype (Le Goff & Noblet 2001). In the present study, the apparent digestibility of crude nutrients was influenced by the period as well as by the diet. The period influenced the digestibility of crude protein (Studies 1 and 2) and crude fat (Study 2). Consistent to the present study, Le Goff & Noblet (2001) also observed an improved digestibility of organic matter, energy and crude protein for adult sows compared to growing pigs. The data from the present experiment showed in most instances a positive effect of increasing BW on apparent digestibility, comparable with the results of Fernández *et al.* (1986) and Le Goff & Noblet (2001), where adult sows showed a superior digestibility of nutrients compared to growing pigs. In contrast, Kass *et al.* (1980) found a negative effect of increasing BW on digestive capacity. Freire *et al.* (2000) and Acciaioli *et al.* (2011) concluded that pigs are able to improve their digestive ability with increasing age. Longland *et al.* (1994) stated that the immature gut micoflora in young pigs is responsible for the decreased apparent digestibility of some nutrients. These findings were in good accordance with the present study and may be used as explanation for the current results.

Acciaioli *et al.* (2011) reported a significant increase ($P<0.01$) in crude protein digestibility of pigs of the same age, but different breeds, parallel to the increase of the lysine level in the diet. These findings were in accordance with the results of the present N balance studies.

The apparent digestibility of crude protein was with 4 % (Study 1), respectively 5 % (Study 2), significantly higher (*P*<0.05) in pigs receiving Diet 2 than in pigs consuming Diet 1. In addition, in the present study the digestibility of the organic matter was significantly higher for Diet 2 and 3 than for Diet 1, but only for Study 1. In contrast to the apparent digestibility of crude protein and organic matter, the digestibility of crude fat decreased with increasing dietary AA content. Morales *et al.* (2002) discussed that digestibility was markedly influenced by the animal breed and to a lesser extent by the diet. In general, the present studies delivered partly inconsistent results; there was no firm evidence for an improvement of N retention and/or apparent digestibility of boars consuming diets with increased AA levels.

In the present investigation, growth performance of boars was mainly affected by the environmental impact (location) of the three pig performance test centres in both experiments. In Experiment 2 the type of sire line was another important factor. These effects were superimposed by several interactions between location×diet, location×sire line, diet×sire line and location×diet×sire line. Morrison *et al.* (2003) stated that housing effects, like reduced feeding space, affected growth performance of entire male pigs. The authors also assumed that other factors such as reduced pen space and, as a consequence, increased social stress could influence the performance. According to Bolhuis *et al.* (2006) pigs might respond to a negative change in environmental conditions by a reduction in weight gain depending on their coping behaviour. In Experiment 1 there were striking interactions between location×diet, location×sire line and diet×sire line for FCR. As in the N balance studies, the diet had no single effect on any of the observed parameters in Fattening Experiment 1. These results indicated the already mentioned presumption that the tested range in dietary AA content was obviously too small to induce effects on growth performance. The sire line had also no significant influence on the growth performances and feed intake exceptional of the boars in Location 3 fed Diet 3. The mentioned group of boars had a 15 % worse FCR for Pi 2 compared Pi 1. The FCR in Location 3 was in total less favourable than in Location 1 or 2. The reason was a defined lower DWG caused by a lower feed intake; the poorer FCR affects in particular boars fed Diet 3.

In Experiment 2, DWG and FCR were influenced by location×diet, location×sire line and location×diet×sire line. As opposed to Experiment 1, the type of sire line and diet influenced the DWG and FCR (*P*<0.01), which is determined arithmetically. Duroc crossbreed pigs exhibited an improved growth performance compared to Pi 3 crossbreeds, independent of the used diet or location. Several authors mentioned the superior growth performance of Duroc terminal sired pigs compared to other crossbreed pigs, McGloughlin *et al.* (1988) outlined that Duroc crosses grew faster and had an advantageous FCR compared to Landrace or Large White sired pigs. Moreover, Latorre *et al.* (2003) found improved growth rates and FCRs for Duroc progeny which fit together with the performance results of Du crosses in the present study. Furthermore, there are no clear indications of a positive or negative effect of an increased AA level of the diet on growth performance. To some extent, it seems that an increased AA concentration even had a negative effect on the DWG of some boars in the current experiments. As justified by AA analysis the target AA concentrations of the diets were entirely met. Therefore, an unintended variation in dietary AA levels can be excluded as a possible reason for the lack of performance response to the graded AA levels.

Gatel & Grosjean (1992) and van Lunen & Cole (1996) stated that increasing the AA content of the diet led to a significant improvement of performance, but only up to a certain AA value. If the AA level was increased further on, the growth rate of the pigs would plateau at first and afterwards it would decrease. These findings were in good accordance with the decreased DWG for Du crossbreed boars consuming Diet 3 compared to those fed Diet 1 in Experiment 2. Therefore, the authors suggest that an oversupply with lysine might cause a growth depression in some types of crossbreed pigs.

In Fattening Experiment 2 measurable significant interactions were found between the location, the diet and the sire line for DGW and as a result for FCR of the boars. These significant results are caused by the amount of feed intake. For health grounds, the average daily feed intake of boars housed in Location 2 was significantly lower than for those in Location 1 or 3. For that reason, it was impossible for the pigs raised in Location 2 to realise higher DGW with this low amount of feed intake. The mean DWG of boars reared in Location 2 is significantly lower than the DWG for boars for both sire lines housed in Location 1 or 3. The low feed intake level also caused the interaction between location and sire line. Induced by the low feed intake, the Du crossbreeds with normally superior growth potential were not able to realise their full performance potential and therefore showed only growth rates like the Pi 3 crosses.

In conclusion, the tested range of increasing dietary AA concentrations was on an overall basis insufficient to influence the N retention and the performance of pigs during the growth period. Only the N retention of Duroc sired boars was positively influenced by an increased AA level. Therefore, it seemed to be unnecessary to increase the dietary AA concentration in diets for growing boars generally above the AA levels used in Diet 1 to achieve maximum performance. Furthermore the decisive impact of the type of sire line, in particular on the growth performance, was authenticated. In addition, the significant influence of the environmental impact (location) on animal performance was confirmed and the nature of these effects needs to be studied further.

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