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# Effects of dietary-reduced nitrogen (N) and phosphorus (P) on N and P balance, retention and nutrient digestibility of contemporary fattening pigs fed *ad libitum*

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**ABSTRACT**

The reduction of nitrogen (N) and phosphorus (P) in fattening pigs' diets is one possible approach to lower N and P excretion in livestock farming relative to N and P intake. Due to the implementation of the European Nitrates Directive and the consecutive amendments to the German fertiliser legislation since 2017, *N*- and *P*-reduced diets for fattening pigs are becoming more and more important and are increasingly used in practice. To investigate the effects of such diets on N and P balance and retention as well as on nutrient digestibility of contemporary fattening pigs, a balance experiment was performed with eight barrows (average live weight = 61.5 ± 2.1 kg) which were surgically fitted with a simple T-cannula at the terminal ileum. The pigs received a control diet meeting nutrient requirements (CON) and an *N*- and *P*-reduced diet (NPred) *ad libitum* ($n = 4$/diet) in a 3-phased feeding regimen (3 weeks/phase). In the last week of each phase, faeces and urine were collected quantitatively for 5 days followed by a 2 × 12 hours collection of ileal digesta. Daily feed intake, live weight gain and feed-to-gain ratio did not differ between CON and NPred. NPred-fed pigs consumed 10.5% ($p = 0.006$) and excreted 28.3% ($p = 0.028$) less N than CON-fed pigs. Phosphorus excretion was lowered by 15.1% in NPred-fed pigs ($p = 0.012$). N and P retention did not differ between CON and NPred, but were elevated in comparison to other studies. N and P efficiency, expressed as nutrient retention divided by nutrient intake, was higher in NPred – than CON-fed pigs (N: 68 vs 60%, P: 54.2 vs 49.3%). Apparent post-ileal digestibility coefficient ($DC_{post\text{-}ileal}$) and apparent total tract digestibility coefficient ($DC_{total}$) of crude protein were higher in NPred – than CON-fed pigs ($p < 0.013$), but apparent precaecal digestibility coefficient ($DC_{pc}$) of crude protein was unaffected by diet. $DC_{pc}$, $DC_{post\text{-}ileal}$ and $DC_{total}$ of P were similar for CON- and NPred-fed pigs. NPred-fed pigs showed an elevated $DC_{pc}$ and $DC_{total}$ of organic matter, N-free-extractives and starch compared to

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CON-fed pigs. $DC_{pc}$ of calcium was also higher in NPred-fed pigs. In conclusion, the results suggest that *N*- and *P*-reduced feeding of fattening pigs remains an effective strategy to lower the N and P release into the environment. Furthermore, results indicate that *N*- and *P*-reduced feeding leads to a higher N and P efficiency in contemporary fattening pigs.

## 1. Introduction

Excessive release of nitrogen (N) and phosphorus (P) leads to severe environmental problems: Eutrophication of surface waters, depletion of non-renewable phosphate resources, contamination of groundwater, soil acidification and greenhouse gas emission (Jongbloed 1987; Daniel et al. 1998; Cordell et al. 2009; Lautrou et al. 2022). Agricultural fertilisation with the use of manure contributes to a large extent to these inputs (BMEL 2020). In order to protect the environment, a reduction of N and P release is indispensable and therefore integrated in form of the Nitrates Directive into European law (Council Directive 91/676/EEC 1991). Due to persistent nitrate surpluses, an infringement proceeding was conducted against Germany between 2013 and 2023, resulting in amendments to the German Fertiliser Ordinance in 2017 and 2020 (BMEL 2017b). Due to these legal restrictions, pig farmers in Germany are increasingly obliged to minimise N and P excretion per pig in order to comply with the maximum nutrient release limits per hectare while maintaining the same number of animals. Different feeding strategies for growing pigs have been developed in the last decades which show that animal nutrition has a significant influence on N and P excretion (Jongbloed and Lenis 1992). A precise diet formulation and the minimisation of safety margins are necessary to feed the pigs as closely as possible to their requirements in order to avoid nutrient surpluses in manure (Jongbloed and Lenis 1992). The addition of crystalline amino acids to pigs' diets represents a possibility to reduce dietary crude protein (CP) concentration while meeting requirements of essential amino acids (Markert et al. 1993; Esteves et al. 2021). Furthermore, concept of phase-feeding is recommended, to adjust the nutrient content of a diet to the growth state and performance of the pigs instead of providing a single diet throughout the entire fattening period (Dourmad and Jondreville 2007).

*N*- and *P*-reduced diets are established for several years. In Germany, they are explicitly mentioned in the German Fertiliser Ordinance (BMEL 2017b). Additionally, practical instructions and recommendations are made by the German Agricultural Society (DLG 2019). Due to further amendments in the sector of agricultural fertilisation, e.g. compulsory preparation of farmgate balances (Van Beek et al. 2003; BMEL 2017a), *N*- and *P*-reduced feeding of fattening pigs will be used more and more in the future. It is therefore of considerable interest to scientifically investigate the effects of this feeding concept on pigs. On the one hand, several performance trials were conducted in the last few years which showed that recommended dietary N and P reductions nevertheless lead to high growth performance (Friggemann et al. 2019; Meyer and Vogt 2019a, 2019b). On the other hand, the data base on N and P balance and nutrient digestibility is meanwhile about 30 years old (GfE 2006). Since the breeding progress in the meantime led to an increased performance potential (Merks 2000; Kratz 2003), the question arises how *N*-

and *P*-reduced feeding affects N and P balance, retention and nutrient digestibility of contemporary fattening pigs. In order to clarify this question, a trial was conducted determining nutrient digestibility and balance and employing a full body fractionation and analysis at the end of the experiment. The results of the full body analysis are not part of this paper, but subject of a second publication.

## 2. Material & methods

The trial was conducted at the Friedrich-Loeffler-Institut (FLI) in Braunschweig, Germany in accordance with the European Community regulations concerning the protection of experimental animals and the guidelines of the German Animal Welfare Act and was approved by the Lower Saxony State Office for Consumer Protection and Food Safety (LAVES), Oldenburg, Germany (file number 33.19 -42502-04-20/3351).

### 2.1. Experimental diets

Two experimental diets were designed, a control diet (CON) meeting nutrient requirements of fattening pigs according to the recommendations of the Society of Nutritional Physiology (Society of Nutrition Physiology 2006) and a diet reduced in N and P concentration (NPred) oriented at the recommendations of the German Agricultural Society (DLG 2019). Diets, based on wheat, barley and soybean meal, were applied in a 3-phased feeding regimen (3 weeks/phase). Pigs had *ad libitum* access (24 hours daily) to feed and water. All diets were given in meal form. Dietary composition and nutrient concentrations are presented in Tables 1–3. Targeted nutrient concentrations are given as supplementary material S2. Chromium oxide ($Cr_2O_3$) was added to the diets as an indigestible marker [1 g/kg diet, as-fed basis]. No exogenous phytases were added. Dietary transition between fattening phases was carried out without adaptation.

### 2.2. Animals, housing & adaptation phase

Twelve barrows (BHZP db. Viktoria x Piétrain) with an initial live weight (LW) of 20.4 ± 1.9 kg (mean ± SD) were obtained from a commercial pig farm and housed individually in solid floor pens equipped with nipple drinkers and troughs. Wood shavings were used as bedding material and coffee wood as enrichment material. The stable was equipped with an automated temperature control system and a natural light system (windows). During the stay in the floor pens, pigs were able to move together outside their pens daily. The first 3.5 weeks after the arrival were used as an adaptation phase, where the pigs were habituated to staff and flatdeck units through positive conditioning. Based on the training success and health concerns, eight pigs were selected for the trial at the end of the adaptation phase and surgically fitted with a simple T-cannula at the terminal ileum (average LW 32.7 ± 2.7 kg). The T-cannula, the fixing rings and cap were produced from titanium and polytetrafluoroethylene (details are provided in supplemental material S1). No antibiotic treatment was used in order to maintain the gastrointestinal microbiome. After surgery, pigs were allowed a 4-week convalescence period prior to the actual experiment.

**Table 1.** Composition [g/kg, as-fed basis] of the control (CON) and the diet with reduced nitrogen and phosphorus concentrations (NPred) for fattening pigs in a 3-phased feeding regimen.

| | Phase I | | Phase II | | Phase III | |
|---|---|---|---|---|---|---|
| | CON | NPred | CON | NPred | CON | NPred |
| Barley | 405.9 | 423.7 | 674.7 | 685.8 | 670.1 | 682.1 |
| Wheat | 364.5 | 419.1 | 144.8 | 219.7 | 189.7 | 249.9 |
| Soybean meal | 186.6 | 114.1 | 137.0 | 50.4 | 96.8 | 26.4 |
| Soybean oil | 20.0 | 20.0 | 20.0 | 19.9 | 20.0 | 19.9 |
| Monocalcium phosphate | 2.3 | 0.4 | 2.8 | 0.9 | 2.8 | 0.9 |
| Calcium carbonate | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 |
| L-Lysine | 0.2 | 2.3 | 0.2 | 2.8 | 0.0 | 1.7 |
| L-Threonine | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| DL-Methionine | 1.8 | 1.7 | 1.8 | 1.8 | 1.8 | 1.7 |
| L-Tryptophan | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.6 |
| Premix[†] | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 | 15.0 |
| Chromium oxide ($Cr_2O_3$) | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

[†]Phosphorus-free mineral and vitamin premix (Deutsche Vilomix Tierernährung GmbH, Neuenkirchen-Vörden, Germany) provided per kg of complete diet: Calcium 3.5 g, sodium 1.6 g, magnesium 0.3 g, vitamin A 6,480 IU, vitamin D3 1,200 IU, vitamin E 36 mg, vitamin B1 1.3 mg, vitamin B2 5.1 mg, vitamin B6 2.6 mg, vitamin B12 25.5 µg/µg, vitamin K3 2.6 mg, niacinamide 17 mg, pantothenic acid 10.2 mg, choline chloride 150 mg, iron (sulphate monohydrate) 120 mg, copper (sulphate) 15 mg, manganese (oxide) 80.1 mg, zinc (oxide) 75 mg, iodine (calcium iodate) 2 mg, selenium (sodium selenite) 0.4 mg.

**Table 2.** Analysed concentration [g/kg, as-fed basis] of nutrients in a control diet (CON) and a diet with reduced nitrogen and phosphorus concentrations (NPred) for 8 fattening pigs in a 3-phased feeding regimen.

| | Phase I | | Phase II | | Phase III | |
|---|---|---|---|---|---|---|
| | CON | NPred | CON | NPred | CON | NPred |
| Dry matter | 879.9 | 879.9 | 884.0 | 883.8 | 884.3 | 883.0 |
| ME[†] [MJ/kg] | 13.4 | 13.4 | 13.3 | 13.3 | 13.3 | 13.3 |
| Crude protein | 168.2 | 143.8 | 156.8 | 126.6 | 137.8 | 114.0 |
| Lysine | 9.1 | 7.4 | 7.4 | 7.0 | 6.1 | 5.1 |
| Pcd lysine[§] | 7.3 | 5.8 | 5.6 | 5.5 | 4.5 | 3.8 |
| Pcd lysine[§] : MJ ME | 0.5 | 0.4 | 0.4 | 0.4 | 0.3 | 0.3 |
| Calcium | 5.2 | 4.7 | 5.4 | 5.0 | 4.8 | 4.1 |
| Phosphorus | 5.5 | 4.6 | 5.5 | 4.9 | 4.3 | 3.8 |
| Pcd phosphorus[§] | 1.7 | 1.3 | 1.6 | 1.5 | 1.5 | 1.5 |
| Calcium : pcd phosphorus[§] [1:] | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 |
| Crude ash | 41.6 | 37.6 | 44.1 | 38.2 | 40.8 | 35.6 |
| Ether extract | 41.9 | 45.0 | 42.9 | 43.8 | 44.7 | 44.8 |
| Crude fibre | 42.5 | 42.8 | 43.2 | 42.8 | 43.1 | 42.9 |
| aNDFom[#] | 161.6 | 138.9 | 167.9 | 166.7 | 188.3 | 204.2 |
| ADFom[¶] | 46.4 | 44.8 | 52.9 | 50.7 | 52.0 | 48.4 |
| Starch | 434.3 | 469.5 | 427.6 | 467.8 | 444.3 | 501.0 |
| Sugar | 34.8 | 29.8 | 32.5 | 22.2 | 25.0 | 19.5 |
| Phytase activity [FTU/kg] | 396 | 496 | 303 | 416 | 262 | 352 |

[†]ME, metabolisable energy, calculation according to Equation 2 in ([GfE] Gesellschaft für Ernährungsphysiologie 2008): $ME_S$ (MJ/kg DM) = (0.021503 × crude protein) + (0.032497 × ether extract) − (0.021071 × crude fibre) + (0.016309 × starch) + (0.014701 × organic residue), all values expressed as g/kg dry matter; [§]Pcd, precaecal digestible, determination based on the calculated apparent precaecal digestibility coefficient via marker method; [#]aNDFom, α-amylase treated neutral detergent fibre expressed without residual ash; [¶]ADFom, acid detergent fibre expressed without residual ash.

### 2.3. *Experimental setup*

Pigs were evenly allotted, based on live weight, to the experimental diets CON ($n = 4$) and NPred ($n = 4$). The trial started with the first day of feeding the experimental diets (LW =

**Table 3.** Analysed concentration [g/kg, as-fed basis] of amino acids (AA) in a control diet (CON) and a diet with reduced nitrogen and phosphorus concentrations (NPred) for 8 fattening pigs in a 3-phased feeding regimen.

| | Phase I | | Phase II | | Phase III | |
|---|---|---|---|---|---|---|
| | CON | NPred | CON | NPred | CON | NPred |
| Sum of AA | 176.4 | 131.4 | 151.6 | 120.7 | 137.8 | 107.3 |
| Essential amino acids | | | | | | |
| Cysteine | 3.0 | 2.6 | 2.7 | 2.5 | 2.7 | 2.3 |
| Histidine | 4.4 | 3.4 | 3.8 | 2.7 | 3.4 | 2.4 |
| Isoleucine | 7.2 | 4.9 | 6.3 | 4.6 | 5.4 | 3.8 |
| Leucine | 12.5 | 9.1 | 10.7 | 8.1 | 9.5 | 7.3 |
| Lysine | 9.1 | 7.4 | 7.4 | 7.0 | 6.1 | 5.1 |
| Methionine | 4.7 | 3.7 | 2.9 | 3.5 | 3.2 | 2.6 |
| Phenylalanine | 8.5 | 6.1 | 7.5 | 5.4 | 6.9 | 5.3 |
| Threonine | 7.7 | 6.6 | 7.1 | 6.0 | 6.5 | 5.3 |
| Tryptophan | 2.6 | 2.2 | 2.9 | 2.3 | 2.6 | 1.9 |
| Tyrosine | 5.7 | 4.0 | 4.9 | 4.1 | 4.5 | 3.3 |
| Valine | 8.6 | 6.2 | 7.5 | 6.2 | 7.1 | 5.5 |
| Nonessential amino acids | | | | | | |
| Alanine | 7.4 | 5.5 | 6.4 | 4.9 | 5.6 | 4.4 |
| Arginine | 11.7 | 7.5 | 9.5 | 6.4 | 8.0 | 5.6 |
| Aspartic acid | 16.0 | 10.1 | 13.1 | 8.5 | 11.1 | 7.1 |
| Glutamic acid | 41.5 | 32.1 | 36.1 | 29.5 | 34.1 | 28.0 |
| Glycine | 7.6 | 5.6 | 6.6 | 5.3 | 6.0 | 4.6 |
| Proline | 12.6 | 10.4 | 11.9 | 10.6 | 11.6 | 10.1 |
| Serine | 8.3 | 6.1 | 7.2 | 5.6 | 6.3 | 4.6 |

61.5 ± 2.1 kg, mean ± SD). The experimental procedures were the same for each fattening phase and are presented in Figure 1.

Each pig remained in its feeding group for the entire trial. During collection periods, pigs were housed individually in flatdeck units (1.2 × 1.8 m) in an environmentally controlled room (temperature 19.7 ± 0.4°C, 12 h/d light program). In flatdeck units, feed and water were provided *ad libitum* (24 hours per day) via two separate troughs and their consumption was determined daily. Pigs were weighed when entering and leaving the flatdeck units. Additionally, LW was measured immediately after the 5-day quantitative collection period in flatdeck units. Pigs were slaughtered with an average LW of 123.3 ± 7.5 kg in the experimental abattoir of the Institute of Animal Nutrition,

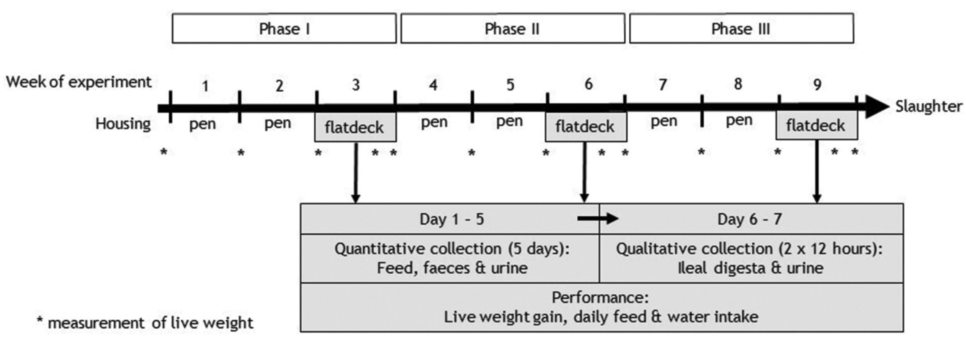


**Figure 1.** Experimental setup of the balance trial with barrows fed the control diet (CON) and the diet with reduced nitrogen and phosphorus concentrations (NPred) in a 3-phased feeding regimen.

Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health, Braunschweig.

### 2.4. Sample collection

Faeces were collected freshly after defaecation from flatdeck floor and directly stored at −20°C. Faecal material was pooled per pig for each collection period. Ileal digesta was collected from 7.30 am to 7.30 pm via plastic bags which were fixed to the barrel of the T-cannula with elastic bands. Bags were changed as soon as they were filled. In total, 10 ml of formic acid (2.5 M) were added to the ileal digesta samples when changing the bags to prevent protein and amino acid loss due to microbial fermentation. Ileal digesta samples were pooled per pig and phase and stored at + 4°C during each collection period. After each 2 × 12 hours collection, digesta samples were immediately freeze-dried. After sampling, faeces and ileal digesta were weighed and thoroughly blended prior to lyophilisation. Urine was collected via two containers placed below every flatdeck unit, each containing 250 ml or 125 ml of formic acid (2.5 M) for 5-day collection or 2 × 12-hours collection, respectively. Each container was equipped with a sieve including glass wool to avoid an inclusion of gross particles. During both, the 5-day and 2 × 12-hours collection, urine was weighed daily, aliquots were taken (1% of daily urine amount) and pooled per pig and phase. Pooled samples were stored at −20°C and filtered through glass wool prior to chemical analyses. Feed samples were collected daily during collection period and pooled per pig and feeding phase. Afterwards, the individual samples were pooled again per phase and diet. Dried faeces, dried ileal digesta and feed samples were ground to pass a 1 mm sieve (ZM 100, RETSCH GmbH, Haan, Germany) or were milled dust fine (MM 400, RETSCH GmbH, Haan, Germany) for amino acid analysis, respectively. LW was recorded weekly and directly before and after each collection period. Feed and water intake were measured daily for each pig during the collection period.

### 2.5. Analyses

Collected samples were analysed according to the methods of the Association of German Agricultural Analytic and Research Institutes (VDLUFA 2012).

#### 2.5.1. Feed, faeces and ileal digesta

Nitrogen was measured using the method of Dumas (method number 4.1.2) and multiplied with factor 6.25 to get the CP concentration. Dry matter, ether extract, crude fibre and crude ash were analysed according to methods 3.1, 5.1.1, 6.1.1 and 8.1, respectively. Furthermore, acid detergent fibre (ADF) and neutral detergent fibre (NDF) were determined using method 6.5.2 and 6.5.1, respectively. ADF and NDF were expressed without residual ash and NDF determination included pretreatment with amylase (ADFom, aNDFom). Metabolizable energy (ME) in the diets was calculated using dietary nutrient concentrations analysed by proximate analysis (Equation (2), (GfE 2008)). Phosphorus (P), calcium (Ca), magnesium (Mg), sodium (Na), zinc (Zn), copper (Cu), manganese (Mn) and iron (Fe) were determined by optical emission spectrometry with inductively coupled plasma (ICP-OES Quantima; GBC Scientific Equipment Pty. Ltd., Melbourne, Vic, Australia) according to method 10.8.2. For $Cr_2O_3$ analyses in diets, faeces and ileal digesta, samples were prepared according to (Williams et al. 1962) and quantified by ICP-OES. Amino acids were analysed by ion-exchange chromatography using an Amino Acid Analyzer (Biochrom 30+, Biochrom Ltd.). Tryptophan was determined by HPLC with fluorescence detection according to method number 4.11.2. Starch in feed was analysed polarimetrically according to method number 7.2.1. Additionally, starch concentration of feed, faeces and ileal digesta was determined by enzymatic method (method 7.2.5) for digestibility calculation. Sugar was determined according to method 7.1.1. Endogenous phytase activity in the diets was determined according to DIN EN ISO 30,024:2009–11.

#### 2.5.2. Urine

Urine was analysed for N content employing the Kjeldahl method (method number 4.1.1). Furthermore, minerals (P, Ca, Mg, Na) and trace elements (Zn, Cu, Mn, Fe) were determined by ICP-OES (method number 10.8.2).

### 2.6. Calculations

Live weight gain (LWG) was determined as the difference between LW at the end of the phase minus LW at the beginning of the phase divided by days of phase. Daily feed provision and refusals were used to calculate daily feed intake (DFI) per pig. The same procedure was applied to daily water intake (DWI) during the collection periods in flatdeck units. Feed-to-gain ratio (FGR) is expressed as kg feed intake per kg LWG for each fattening phase.

Apparent total tract digestibility coefficient ($DC_{total}$) and apparent precaecal digestibility coefficient ($DC_{pc}$) based on marker method were calculated using following equations (Kirchgeßner et al. 2014):

$$DC_{total}, DC_{pc}[\%] = 100 - \left(\frac{marker_{diet} \cdot nutrient_{faeces/digesta}}{marker_{faeces/digesta} \cdot nutrient_{diet}}\right) \cdot 100$$

where concentrations of indigestible marker and nutrient in diet, ileal digesta and faeces were given as [g/kg DM].

Apparent post-ileal digestibility coefficient ($DC_{post\text{-}ileal}$) was calculated according to (Baumgärtel et al. 2008):

$$DC_{post-ileal}[\%] = 100 - \left(\frac{marker_{digesta} \cdot nutrient_{faeces}}{marker_{faeces} \cdot nutrient_{digesta}}\right) \cdot 100.$$

Based on quantitative determination of nutrient intake and excretion via faeces and urine, nutrient retention was calculated as follows according to (Otten et al. 2013) [all values expressed as g/d]:

$$Retention = intake - excretion_{urine} - excretion_{faeces}.$$

Nutrient efficiency was determined by using calculated values for retention and intake [both in g/d]:

$$Efficiency[\%] = \frac{retention}{intake} \cdot 100.$$

Metabolizable energy (ME) was calculated using concentrations of digestible CP, digestible ether extract and digestible organic residue (calculation using $DC_{total}$) according to (Equation (3), (GfE 2006)).

### 2.7. Statistics

Statistical analyses were performed using the PROC MIXED procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC) using a restricted maximum likelihood model (REML). Phase, diet and their interaction were defined as fixed factors and phase was used as repeated measurement. Co-variance structure was chosen according to the corrected Akaike's information criterion (AICC). An adjusted Tukey-Kramer-test was applied as *post-hoc* procedure. *P*-values <0.05 were deemed significant and *p*-values <0.1 were regarded as a trend. Results are presented as least square means (LSmeans) and pooled standard error of means (PSEM).

## 3. Results

### 3.1. Diet composition

Analysed nutrient concentrations of the diets are listed in Tables 2 and 3. Although the analysed CP concentration in all diets was lower than targeted, the relative difference between CON and NPred was maintained in all three fattening phases and the targeted continuous decrease in CP concentration over the trial was successful. It is noticeable that the total lysine concentration was 9 and 26% lower than planned in phase I, 18 and 22% lower in phase II and 19 and 32% lower in phase III for CON and NPred, respectively. The content of P was higher than targeted in phase I and II for both, CON and NPred. In phase III, analysed P concentrations fit well to the targeted values. ME concentrations of the diets were higher than the targeted values in phase II and III. Dietary concentrations of magnesium, sodium and trace elements are provided as supplementary material (Table S3).

### 3.2. Performance & health

All pigs recovered successfully from surgery and remained healthy during the experiment. Performance was unaffected by the diet (Table 4). CON and NPred achieved almost similar LW at the beginning of each fattening phase as well as at the end of the experiment (= slaughter). LWG was highest during phase II ($p = 0.007$). DFI increased linearly from phase I to phase II to phase III ($p < 0.001$). Feed-to-gain ratio was lowest in phase II ($p = 0.041$). DWI was unaffected by phase and diet.

### 3.3. Nutrient balance

The amount of faecal and urinary excretion during the 5-day quantitative collection in flatdeck units [kg/5 days] did not differ between CON and NPred (Table 5). Faecal excretion differed between the feeding phases ($p < 0.001$) and was highest in phase II.

**Table 4.** Performance of eight fattening pigs in a balance trial fed a control diet (CON) or a diet with reduced concentrations of nitrogen and phosphorus (NPred) in a 3-phased feeding regimen. Data are presented as LSmeans ($n = 4$/diet).

| | Phase I | | Phase II | | Phase III | | Slaughter | | | *p*-values | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CON | NPred | CON | NPred | CON | NPred | CON | NPred | PSEM† | Phase | Diet | Phase x Diet |
| $LW_{start}$§ [kg] | 61.1 | 61.8 | 80.0 | 79.5 | 102.3 | 102.1 | 123.3 | 123.3 | 1.7 | <0.001 | 0.998 | 0.997 |
| LWG# [g/d] | 900 | 842 | 1062 | 1076 | 999 | 1011 | – | – | 41 | 0.007 | 0.900 | 0.729 |
| DFI¶ [kg/d, as fed] | 3.1 | 3.2 | 3.4 | 3.5 | 3.6 | 3.8 | – | – | 0.3 | <0.001 | 0.403 | 0.496 |
| F:G$ [kg feed/kg LWG] | 3.5 | 3.8 | 3.3 | 3.3 | 3.6 | 3.8 | – | – | 0.1 | 0.041 | 0.194 | 0.698 |
| DWI+ [l/d] | 6.8 | 6.4 | 7.1 | 6.9 | 6.6 | 6.7 | – | – | 0.3 | 0.455 | 0.752 | 0.744 |

†PSEM, pooled standard error of means; §$LW_{start}$, live weight (LW) at the beginning of the phase; #LWG, live weight gain; ¶DFI, daily feed intake; $F:G, feed-to-gain ratio; +DWI, daily water intake.

**Table 5.** Amount of excretions and mean live weight of barrows during 5-day collection periods for calculation of nutrient balance. Pigs were fed a control diet (CON) or a diet with reduced concentrations of nitrogen and phosphorus (NPred) in a 3-phased feeding regimen ($n = 4$/diet).

| | Phase I | | Phase II | | Phase III | | | *p*-values | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CON | NPred | CON | NPred | CON | NPred | PSEM† | Phase | Diet | Phase x Diet |
| Excretions [kg/5d] | | | | | | | | | | |
| Faeces (fresh matter) | 7.49 | 6.88 | 10.99 | 9.98 | 9.38 | 9.01 | 0.45 | <0.001 | 0.482 | 0.685 |
| Faeces (dry matter) | 1.70 | 1.70 | 2.63 | 2.39 | 2.22 | 2.16 | 0.09 | <0.001 | 0.609 | 0.470 |
| Urine | 12.52 | 12.25 | 12.22 | 10.44 | 11.28 | 10.21 | 1.11 | 0.183 | 0.654 | 0.674 |
| Mean live weight [kg] | 77.4 | 77.0 | 99.7 | 99.7 | 120.5 | 121.2 | 1.8 | <0.001 | 0.976 | 0.904 |

†PSEM, pooled standard error of means.

Mean LW during 5-day quantitative collection was similar between CON and NPred (Table 5).

Pigs fed with NPred consumed 10.5% less N and excreted 28.3% less N than CON-fed pigs (Table 6). Reduced absolute N excretion was observed in both, faeces and urine. Total N intake was significantly lower in phase III than phase II (71.9 vs 82.0 g/d). Total and faecal N excretion were elevated in phase II compared to phase I and III. Daily N retention, however, did not differ between the diets but was significantly higher in phase I than phase III (52.3 vs 46.3 g/d). N efficiency was higher in NPred – than CON-fed pigs (68.4 vs 60.6%).

NPred-fed pigs consumed and excreted less P than CON-fed pigs (Table 6). However, the lower P intake was only shown as a statistical trend. The reduction in P excretion of the NPred-fed pigs was due to a reduction in urinary, but not in faecal excretion. While urinary P excretion increases linearly from phase I to phase II to phase III in CON-fed pigs, it remained at a low level in NPred-fed pigs giving rise to significant interactions between phase and diet. P intake, total and faecal excretion were elevated in phase II compared with phase I and III. As already mentioned for N, absolute P retention was unaffected by diet. Absolute P retention was significantly lower in phase III than phase I and II. Additionally, NPred-fed pigs showed a higher P efficiency than CON-fed pigs (54.2 vs 49.3%). The amount of Ca intake was similar for CON and NPred, as well as the amount of total excretion (Table 6). Ca excretion via faeces was lower for NPred than CON. Ca intake, total and faecal excretion were elevated in phase II. Urinary Ca

**Table 6.** Nutrient balance for nitrogen, phosphorus and calcium of barrows fed a control diet (CON) or a diet with reduced concentrations of nitrogen and phosphorus (NPred) in a 3-phased feeding regimen. Data are presented as LSmeans.

| | Phase I | | Phase II | | Phase III | | | *p*-values | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CON | NPred | CON | NPred | CON | NPred | PSEM[†] | Phase | Diet | Phase x Diet |
| Nitrogen [g/d] | | | | | | | | | | |
| Intake | 82.0 | 75.7 | 88.9 | 75.1 | 74.9 | 68.9 | 2.4 | 0.024 | 0.006 | 0.445 |
| Total excretion | 29.2 | 24.0 | 37.3 | 25.3 | 30.9 | 20.2 | 1.6 | 0.026 | 0.028 | 0.216 |
| Faecal | 13.1 | 10.6 | 18.9 | 15.0 | 14.9 | 12.5 | 0.9 | 0.002 | 0.008 | 0.811 |
| Urinary | 16.1 | 13.4 | 18.4 | 10.3 | 16.0 | 7.7 | 1.4 | 0.296 | 0.001 | 0.282 |
| Retention | 52.8 | 51.7 | 51.6 | 49.8 | 44.0 | 48.7 | 1.6 | 0.043 | 0.764 | 0.296 |
| Efficiency [%] | 64.8 | 68.4 | 58.3 | 66.3 | 58.7 | 70.5 | 1.4 | 0.096 | 0.031 | 0.109 |
| Phosphorus [g/d] | | | | | | | | | | |
| Intake | 16.7 | 15.1 | 19.4 | 18.0 | 14.7 | 14.2 | 0.5 | <0.001 | 0.073 | 0.721 |
| Total excretion | 7.4 | 6.8 | 10.9 | 9.0 | 7.6 | 6.1 | 0.4 | <0.001 | 0.012 | 0.517 |
| Faecal | 7.0 | 6.7 | 10.3 | 8.9 | 6.7 | 6.0 | 0.4 | <0.001 | 0.106 | 0.588 |
| Urinary | 0.40 | 0.09 | 0.60 | 0.07 | 0.89 | 0.07 | 0.30 | 0.001 | 0.001 | <0.001 |
| Retention | 9.3 | 8.3 | 8.4 | 9.1 | 7.1 | 8.1 | 0.3 | 0.022 | 0.557 | 0.069 |
| Efficiency [%] | 55.8 | 55.0 | 43.6 | 50.5 | 48.5 | 57.0 | 1.5 | 0.004 | 0.014 | 0.102 |
| Calcium [g/d] | | | | | | | | | | |
| Intake | 15.7 | 15.5 | 19.0 | 18.7 | 16.2 | 15.7 | 0.5 | <0.001 | 0.555 | 0.972 |
| Total excretion | 5.2 | 5.5 | 7.6 | 6.6 | 5.8 | 4.9 | 0.3 | <0.001 | 0.121 | 0.296 |
| Faecal | 5.0 | 4.4 | 7.4 | 5.7 | 5.6 | 4.6 | 0.2 | <0.001 | 0.046 | 0.135 |
| Urinary | 0.3 | 1.0 | 0.2 | 1.0 | 0.2 | 0.3 | 0.1 | 0.008 | <0.001 | 0.025 |
| Retention | 10.5 | 10.0 | 11.3 | 12.0 | 10.4 | 10.8 | 0.4 | 0.051 | 0.658 | 0.580 |
| Efficiency [%] | 67.0 | 65.0 | 59.7 | 64.3 | 64.3 | 68.9 | 1.4 | 0.073 | 0.162 | 0.196 |

[†]PSEM, pooled standard error of means.

excretion was affected by the interaction of phase and diet: While urinary Ca excretion remained at a similar level in CON-fed pigs, it was remarkable higher in NPred-fed pigs in phase I and II (1 g/d) but then decreased to a similar level than CON. Ca retention did not differ between CON- and NPred-fed pigs, but was significantly affected by phase. Ca efficiency was unaffected by phase and diet.

## 3.4. Nutrient digestibility

Results for apparent precaecal digestibility coefficient ($DC_{pc}$), apparent post-ileal digestibility coefficient ($DC_{post\text{-}ileal}$) and apparent total tract digestibility coefficient ($DC_{total}$) are presented in Table 7. $DC_{pc}$ of organic matter, N-free extractives, starch and Ca was higher in NPred – than CON-fed pigs. $DC_{post\text{-}ileal}$ of CP was higher in NPred- than CON-fed pigs, whereas $DC_{post\text{-}ileal}$ of N-free extractives was lower in NPred-fed pigs. NPred-fed pigs showed a higher $DC_{total}$ of organic matter, CP, N-free extractives, and starch. For ether extract, this effect could be observed as a statistic trend. Furthermore, $DC_{total}$ of many macro nutrients was influenced by phase. Conspicuously, pigs showed a higher $DC_{total}$ of organic matter, CP and crude fibre in phase I compared to phase II and III. $DC_{total}$ of P was unaffected by diet but showed an increase from phase II to III (as a statistic trend of phase). Additionally, $DC_{total}$ of Ca was higher in NPred – than CON-fed pigs. ME was higher in NPred – than CON-fed pigs (Table 7).

Table 8 shows $DC_{pc}$ of amino acids. $DC_{pc}$ of methionine was affected by interaction of phase and diet. $DC_{pc}$ of isoleucine, arginine, aspartic acid and glycine was

**Table 7.** Apparent precaecal digestibility coefficient ($DC_{pc}$), apparent post-ileal digestibility ($DC_{post\text{-}ileal}$) and apparent total tract digestibility coefficient ($DC_{total}$) calculated via marker method of barrows fed a control diet (CON) or a diet with reduced concentrations of nitrogen and phosphorus (NPred) in a 3-phased feeding regimen. Data are presented as LSmeans ($n = 4$/diet).

| | Phase I | | Phase II | | Phase III | | | *p*-values | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CON | NPred | CON | NPred | CON | NPred | PSEM† | Phase | Diet | Phase x Diet |
| $DC_{pc}$ [%] | | | | | | | | | | |
| Organic matter | 67.7 | 73.0 | 64.0 | 70.1 | 67.8 | 71.8 | 1.2 | 0.131 | 0.001 | 0.823 |
| Crude protein | 74.3 | 73.1 | 70.5 | 70.3 | 70.6 | 70.2 | 1.0 | 0.062 | 0.638 | 0.930 |
| Ether extract | 71.3 | 74.0 | 69.1 | 71.6 | 69.0 | 71.3 | 1.5 | 0.459 | 0.174 | 0.995 |
| N-free extractives | 68.9 | 75.8 | 66.2 | 73.7 | 71.0 | 75.9 | 1.0 | 0.082 | <0.001 | 0.673 |
| Crude fibre | 20.7 | 32.4 | 4.9 | 15.5 | 11.3 | 15.6 | 4.3 | 0.036 | 0.091 | 0.813 |
| aNDFom# | 39.7 | 36.5 | 28.5 | 33.8 | 42.0 | 48.8 | 2.5 | 0.003 | 0.318 | 0.332 |
| ADFom¶ | 15.7 | 24.5 | 14.2 | 20.4 | 17.9 | 15.2 | 4.5 | 0.841 | 0.443 | 0.640 |
| Starch | 89.7 | 93.4 | 85.9 | 88.5 | 88.6 | 92.2 | 0.8 | 0.002 | 0.001 | 0.875 |
| Phosphorus | 32.0 | 28.9 | 29.4 | 31.2 | 35.4 | 38.6 | 2.5 | 0.118 | 0.817 | 0.650 |
| Calcium | 49.0 | 55.3 | 49.2 | 58.1 | 53.5 | 60.8 | 2.1 | 0.260 | 0.007 | 0.908 |
| $DC_{post\text{-}ileal}$ [%] | | | | | | | | | | |
| Organic matter | 49.9 | 46.6 | 47.2 | 44.0 | 43.5 | 40.1 | 1.9 | 0.085 | 0.157 | 0.999 |
| Crude protein | 12.8 | 29.9 | 11.3 | 17.0 | 9.6 | 14.0 | 0.7 | 0.064 | <0.001 | 0.224 |
| Ether extract | −30.7 | −23.6 | −27.6 | −22.0 | −13.8 | −16.3 | 6.9 | 0.432 | 0.674 | 0.872 |
| N-free extractives | 69.4 | 63.5 | 66.1 | 62.0 | 63.4 | 59.0 | 1.4 | 0.051 | 0.008 | 0.889 |
| Crude fibre | 21.1 | 9.9 | 18.4 | 11.7 | 5.7 | 1.8 | 5.7 | 0.277 | 0.279 | 0.901 |
| aNDFom# | 33.3 | 28.7 | 33.2 | 29.9 | 22.3 | 20.2 | 3.5 | 0.085 | 0.413 | 0.968 |
| ADFom¶ | 19.2 | 4.9 | 13.2 | 8.4 | 0.7 | −1.9 | 6.0 | 0.282 | 0.308 | 0.764 |
| Starch | 88.4 | 89.0 | 91.1 | 90.9 | 89.6 | 84.4 | 0.8 | 0.010 | 0.104 | 0.039 |
| Phosphorus | 11.5 | 16.2 | 6.9 | 8.6 | 6.9 | 1.7 | 3.7 | 0.216 | 0.923 | 0.634 |
| Calcium | 10.8 | 13.4 | 4.4 | 8.2 | 1.7 | −5.9 | 4.2 | 0.081 | 0.932 | 0.583 |
| $DC_{total}$ [%] | | | | | | | | | | |
| Organic matter | 83.9 | 85.8 | 81.0 | 83.3 | 82.1 | 83.2 | 0.4 | <0.001 | 0.001 | 0.505 |
| Crude protein | 77.6 | 81.4 | 73.8 | 75.4 | 73.6 | 74.5 | 0.6 | <0.001 | 0.012 | 0.267 |
| Ether extract | 62.7 | 68.6 | 61.1 | 65.6 | 66.0 | 67.1 | 0.8 | 0.022 | 0.051 | 0.089 |
| N-free extractives | 90.5 | 91.3 | 88.6 | 90.0 | 89.6 | 90.1 | 0.3 | 0.005 | 0.019 | 0.570 |
| Crude fibre | 38.0 | 40.1 | 23.4 | 25.7 | 19.4 | 18.8 | 2.0 | <0.001 | 0.584 | 0.852 |
| aNDFom# | 60.1 | 54.7 | 52.6 | 53.7 | 56.2 | 59.5 | 1.3 | 0.030 | 0.824 | 0.063 |
| ADFom¶ | 32.5 | 29.1 | 26.4 | 27.5 | 22.5 | 15.4 | 1.9 | 0.001 | 0.176 | 0.332 |
| Starch | 98.8 | 99.3 | 98.8 | 99.0 | 98.9 | 98.8 | 0.1 | 0.116 | 0.042 | 0.129 |
| Phosphorus | 40.0 | 40.6 | 34.1 | 38.9 | 40.0 | 40.0 | 1.0 | 0.064 | 0.533 | 0.247 |
| Calcium | 55.0 | 61.9 | 51.7 | 62.1 | 54.6 | 58.8 | 1.0 | 0.447 | <0.001 | 0.138 |
| ME [MJ/kg, as-fed basis]§ | 12.8 | 13.2 | 12.3 | 12.6 | 12.6 | 12.6 | 0.1 | <0.001 | 0.002 | 0.088 |

†PSEM, pooled standard error of means; #aNDFom, α-amylase treated neutral detergent fibre expressed without residual ash; ¶ADFom, acid detergent fibre expressed without residual ash; §ME, metabolisable energy, calculation using $DC_{total}$ of crude protein, ether extract and organic residue according to Equation 3 in (GfE 2006).

lower in NPred – than CON-fed pigs. $DC_{pc}$ of sum of AA, histidine, isoleucine, leucine, lysine, phenylalanine, arginine and glycine was affected by phase only. Standardised precaecal digestibility of CP and amino acids is shown in supplementary material S5.

Balance parameters and $DC_{total}$ (based on quantitative calculation) of magnesium, sodium and trace minerals are presented in the supplements (Table S4).

**Table 8.** Apparent precaecal digestibility coefficient ($DC_{pc}$) [%] of amino acids (AA) of barrows fed a control diet (CON) or a diet with reduced concentrations of nitrogen and phosphorus (NPred) in a 3-phased feeding regimen. Data are presented as LSmeans ($n = 4$/diet).

| | Phase I | | Phase II | | Phase III | | | *p*-values | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CON | NPred | CON | NPred | CON | NPred | PSEM[†] | Phase | Diet | Phase x Diet |
| Sum of AA | 80.7 | 76.7 | 75.2 | 75.2 | 75.4 | 74.7 | 1.0 | 0.034 | 0.208 | 0.357 |
| Essential AA | | | | | | | | | | |
| Cysteine | 75.3 | 72.7 | 68.5 | 72.8 | 73.5 | 75.1 | 1.5 | 0.190 | 0.523 | 0.287 |
| Histidine | 82.1 | 78.8 | 76.9 | 75.1 | 77.2 | 75.5 | 1.2 | 0.027 | 0.112 | 0.859 |
| Isoleucine | 80.1 | 74.3 | 75.3 | 72.0 | 73.4 | 70.2 | 0.6 | 0.023 | <0.001 | 0.640 |
| Leucine | 80.1 | 76.3 | 75.6 | 74.5 | 74.5 | 74.1 | 1.1 | 0.047 | 0.162 | 0.510 |
| Lysine | 80.8 | 77.7 | 75.2 | 78.4 | 73.3 | 74.3 | 0.6 | 0.036 | 0.660 | 0.111 |
| Methionine | 89.5 | 88.2 | 78.6 | 85.0 | 84.3 | 84.1 | 1.0 | <0.001 | 0.187 | 0.032 |
| Phenylalanine | 81.0 | 77.0 | 75.3 | 72.9 | 76.3 | 77.1 | 1.0 | 0.007 | 0.112 | 0.216 |
| Threonine | 79.0 | 76.6 | 75.5 | 75.0 | 74.7 | 73.7 | 1.3 | 0.179 | 0.417 | 0.859 |
| Tryptophan | 76.6 | 76.1 | 79.3 | 78.8 | 79.6 | 75.6 | 1.8 | 0.582 | 0.435 | 0.731 |
| Tyrosine | 83.0 | 76.1 | 77.0 | 77.8 | 76.7 | 75.3 | 1.1 | 0.110 | 0.071 | 0.072 |
| Valine | 76.9 | 71.5 | 71.4 | 72.7 | 72.5 | 71.5 | 1.2 | 0.315 | 0.221 | 0.140 |
| Nonessential AA | | | | | | | | | | |
| Alanine | 71.3 | 64.6 | 65.3 | 62.2 | 63.8 | 61.4 | 1.6 | 0.063 | 0.037 | 0.605 |
| Arginine | 85.2 | 80.0 | 80.8 | 74.8 | 78.4 | 75.6 | 0.9 | 0.001 | <0.001 | 0.451 |
| Aspartic acid | 77.8 | 68.0 | 73.1 | 67.2 | 71.4 | 65.9 | 0.8 | 0.206 | <0.001 | 0.524 |
| Glutamic acid | 85.2 | 83.9 | 80.3 | 83.4 | 80.8 | 82.2 | 0.9 | 0.050 | 0.320 | 0.244 |
| Glycine | 70.1 | 62.2 | 62.0 | 58.1 | 62.4 | 55.9 | 1.8 | 0.023 | 0.008 | 0.711 |
| Proline | 80.4 | 78.3 | 73.7 | 75.6 | 76.3 | 76.4 | 1.4 | 0.070 | 0.984 | 0.603 |
| Serine | 77.9 | 71.6 | 71.6 | 70.3 | 71.7 | 69.6 | 1.4 | 0.105 | 0.063 | 0.443 |

[†]PSEM, pooled standard error of means.

## 4. Discussion

In order to investigate the effects of *N*- and *P*-reduced diets on nutrient digestibility, balance and retention in contemporary fattening pigs, a balance trial with eight barrows was conducted.

As expected, N intake was significantly decreased in NPred – compared to CON-fed pigs. As already mentioned, total N intake was in average 10.5% lower in NPred-fed pigs which resulted in a 28.3% lower total N excretion. The effect that the reduction in N excretion was almost three times higher than the actual reduction in N intake, has been reported in the literature (Gatel and Grosjean 1992). The reduction in N excretion occurred mainly via urine: NPred-fed pigs excreted 37.5% less N via urine than CON-fed pigs, while excretion via faeces was 19.0% less. This effect of higher level of reduction via urine than faeces has already been described in other studies (Portejoie et al. 2004; Wang et al. 2020). One explanation for the weak effect on faecal N excretion is the limited effect of dietary N reduction on N digestibility (Cappelaere et al. 2021). The magnitude of the urinary and faecal reduction was in accordance with recent results from (Wang et al. 2020) and (Geicsnek-Koltay et al. 2022). The reduction of dietary CP was associated with a significant higher $DC_{total}$ of CP, but since the majority of amino acid absorption takes place in small intestine (Stein et al. 2007; van der Wielen et al. 2017), $DC_{pc}$ is more precise. The similarity between $DC_{pc}$ of CP in CON- and NPred-fed pigs confirms the previously described claim of (Cappelaere et al. 2021) that dietary CP reduction has only a limited effect on N digestibility. The elevated $DC_{total}$ of CP in NPred-fed pigs appears to be related to the higher $DC_{post\text{-}ileal}$ ($p_{diet}$ < 0.001). The increase of $DC_{post\text{-}ileal}$ led to a decrease in faecal CP excretion. One possible explanation could be that there was less total bacterial mass in the large intestine of NPred-fed pigs, resulting in less microbial protein being synthesised and excreted via faeces. Unfortunately, no information can be provided on the bacterial mass for this trial. However, the higher $DC_{post\text{-}ileal}$ of CP could also be due to the fact that the NPred-fed pigs were able to digest a higher amount of the microbial protein synthesised in the large intestine. While there is widespread scientific agreement that most of the amino acid absorption occurs in the small intestine, it is controversial discussed whether and to which extent pigs are able to absorb amino acids in the large intestine (Metges et al. 2006; Van der Wielen et al. 2017). A study of (Torrallardona et al. 2003) showed that >90% of the microbially synthesised lysine is already absorbed in the small intestine of pigs. It remains questionable whether the NPred-fed pigs were able to absorb microbially synthesised lysine and other amino acids to a greater extent in the large intestine than the CON-fed pigs, since the CON- and NPred-fed pigs showed a similar growth performance. In this context, it should be mentioned that clarifying whether and to which level microbially synthesised lysine can be used for body protein accretion is methodologically very difficult. Although the lysine concentration was lower than targeted in all diets, daily lysine intake was sufficient according to the recommendations of (LWK Niedersachsen 2021). For phase III, daily lysine intake was slightly lower for both, CON- and NPred-fed pigs. Furthermore, daily intake of precaecal digestible lysine was calculated for the complete trial (by using DFI and $DC_{pc}$ of lysine). Compared to the recommendations of (GfE 2006), all pigs were supplied sufficiently with precaecal digestible lysine in phase I and II. In phase III, CON-fed pigs consumed in average 16.3 ± 2.3 g/d, which is close to the recommendation (16.3 g/d), but for NPred it was slightly lower (14.4 ± 0.8 g/d). It can be assumed that the pigs were able to meet their lysine requirements during the whole experiment since no symptoms of an amino acid deficiency, i. e. decreased daily feed intake, reduced growth or increased feed refusals could be observed (NRC 2012). Since lysine represents the first limiting amino acid for growth of pigs, the slight undersupply of NPred-fed pigs in phase III could have led to reduced body N retention in this phase compared to the control group. Results for performance and N retention, however, did not show a difference between both groups. For a final evaluation, the results of the full body analysis have to be expected.

Although the reduction of P intake in NPred-fed pigs has only been observed as a statistic trend, NPred-fed pigs excreted totally 15.1% less P than CON-fed pigs ($p$ = 0.012) (Zhai et al. 2022). reported total faecal P excretion to be 55% of P intake in growing pigs. In this balance trial, we observed nearly similar values for the ratio between faecal P excretion and P intake: 47.4% for CON- and 45.7% for NPred-fed pigs. While faecal P excretion did not differ significantly between the diets, a linear increase of urinary P excretion was observed for CON-fed pigs from phase I to phase II to phase III, while it remained on a low level in NPred-fed pigs ($p_{phase\ x\ diet}$ < 0.001). Jongbloed (1987) described that a continuous low urinary P excretion is typical for diets with lower P concentrations, as in the used NPred diets. Further (Rodehutscord et al. 1999), explained it as a hint that the amount of digested P can be completely used by the pig. In contrast, increasing urinary P excretion suggests that body P is “completely restored” (Rodehutscord et al. 1999) and furthermore indicates that the amount of dietary available P is above nutrient requirement (Jongbloed 1987;

Rodehutscord et al. 1999). Urinary P concentrations between 150 and 400 mg/L indicate a P oversupply (Jongbloed 1987). The increasing urinary P excretion in combination with urinary P concentrations of 166 ± 38, 240 ± 76 and 388 ± 46 mg/L (means ± SD) in phase I, II and III, respectively, suggest a P oversupply in the CON-fed pigs. In contrast, urinary P concentrations of 6 to 16 mg/L indicate a P undersupply (Jongbloed 1987). In NPred-fed pigs, P concentration in urine was constantly between 40 and 45 mg/L, which indicates an adequate dietary P supply. In literature, results of P balance trials show both urinary and faecal excretion are lowered when feeding diets with reduced P content (Varley et al. 2011). Since the reduction of P intake in NPred-fed pigs has been seen only as a statistical trend, also faecal P excretion was not significantly decreased. But in combination with the decreased urinary P excretion, total P excretion was significantly lower in NPred- than CON-fed pigs. Comparable to N, also P is absorbed mainly in small intestine (Zhai et al. 2022). Thus, $DC_{pc}$ is more accurate in comparison to $DC_{total}$. However, no difference in $DC_{pc}$, $DC_{total}$ nor $DC_{post\text{-}ileal}$ of P could be observed between CON and NPred. Some studies reported a lowered P digestibility in pigs fed diets with reduced P concentration (Jendza et al. 2005; Kühn and Männer 2012). Furthermore Aderibigbe et al. (2021), showed an increase of P digestibility with increasing total P concentrations in the diets. However, we could not observe any of the previous mentioned effects. On the one hand, this could be due to a downregulation of P absorption caused by the described P oversupply in the CON-fed pigs (Aderibigbe et al. 2021). On the other hand, the total available amount of P could have been elevated due to the higher activity of endogenous phytase in NPred-diets, since degradation of P bound to phytic acid can be achieved not only by phytases added exogenously to the diet, but also by endogenous phytases found in cereals and soybean meal. In particular, wheat contains a significant higher endogenous phytase activity than barley and soybean meal (Eeckhout and De Paepe 1994). The higher proportion of wheat in the NPred diets compared to the CON diets, could thus explain the higher endogenous phytase activity in the NPred diets. This higher activity could have also led to the higher digestibility of other nutrients in the NPred-fed pigs caused by so-called "extra-phosphoric effects": In a review Selle et al. (2012) described that phytases do not only lead to an increase of P digestibility from 8% to 30% (Aarnink and Verstegen 2007). Furthermore, phytases are able to degrade proteins, carbohydrates and fats which are also bound to phytic acid. In this trial, the higher $DC_{pc}$ and also $DC_{total}$ of organic matter, N-free extractives, starch and Ca could be caused by the endogenous phytase activity. In general, digestibility can be influenced by a variety of factors such as genetics, age, feed composition, phytase activity and pH-value in the gastrointestinal tract (Partanen and Mroz 1999; Otten et al. 2013). Possible is also a change in the composition of the gut microbiota induced by the experimental diets (Niu et al. 2019). All in all, it cannot be fully explained why the digestibility of mentioned nutrients was significantly increased in NPred-fed pigs and why digestibility of organic matter, CP and crude fibre was higher in phase I compared to phase II and III. The higher $DC_{total}$ of CP ($p = 0.021$) and ether extract (statistic trend, $p = 0.051$) in the NPred-fed pigs in combination with the slightly higher concentrations of starch in their diets, lead to the higher amount of ME in the faeces of NPred-fed pigs. This is conclusive, because due to lower urinary N excretion of the NPred-fed pigs, energy loss via urea excretion was lower than in CON-fed pigs. The higher ME concentration relative to N concentration could have been an opportunity for an improved N utilisation in the NPred-fed pigs, resulting in the higher N efficiency compared to the CON-fed pigs.

Since P metabolism is closely related to Ca, Ca surpluses in the diet should be avoided too (Sørensen et al. 2018; Lütke-Dörhoff et al. 2023). The elevated urinary Ca excretion of the NPred-fed pigs indicates a not ideal Ca : P ratio in the diets of phase I and II (Jongbloed 1987). Sørensen et al. (2018) defined a ratio of Ca retention: P retention of 1.4:1 (g/d) as a hint for adequate P: Ca ratio in feed. The ratio in the phase I diets was lower but nearly similar with 1.2:1 and 1.1:1 for NPred and CON, respectively, as well as in the diets of phase II with a ratio of 1.3:1 in both groups. When looking at the ratio of Ca: precaecal digestible P in the diets of phase I and II, ratio was smaller than targeted, but no difference could be observed between CON and NPred too. Because of this lack of difference between CON and NPred, it cannot be assumed that the dietary Ca : P ratio was the reason for higher urinary Ca excretion in NPred-fed pigs. A more likely reason is that the downregulation of Ca absorption as reaction to the reduction of dietary P concentration, was not sufficient (Sørensen et al. 2018). As this effect occurred until phase III, it could be interpreted as an indication that the NPred-fed pigs needed the time of phase I and II to completely adapt their Ca metabolism to the lower dietary P concentration.

Although the NPred-fed pigs consumed less N and P, retention did not differ from CON-fed pigs. Cappelaere et al. (2021) attributed the similar growth performance to this phenomenon. Other authors reported that N retention did not vary between two groups whose diets differed by 3% in CP concentration (Otto et al. 2003). If the reduction was more than 3%, Otto et al. (2003) reported a decrease in N retention. This is confirmed by investigations of (Varley et al. 2011), where a reduction from 20% to 13% dietary CP resulted in a significant decrease of N retention. Caused by the lower N and P intake while showing a similar retention, NPred-fed pigs showed a higher N and P efficiency than CON-fed pigs. (Cappelaere et al. 2021) reported that per percentage point of dietary CP reduction, N efficiency was elevated by 1.6% points. Similar values were observed in our trial, where N efficiency was 68% and 60% for NPred- and CON-fed pigs, respectively, at a difference in dietary CP concentration between 2.5% and 3.0% points. Comparing absolute retention values for N and P, calculated values are almost twice to thrice as high as in comparable studies (Haude 2003; Varley et al. 2011; Otten et al. 2013). Since level of N and P excretions were similar to mentioned studies and additionally, efficiency of nutrient utilisation in the present experiment was comparable to balance studies of (Varley et al. 2011; van der Peet-Schwering et al. 2020), discrepancy was most likely caused by the amount of N and P intake due to the amount of feed intake. While pigs in other studies were given a limited amount of feed per day (provided mostly in two meals), pigs in the present trial were given *ad libitum* access to the diets (= 24 hours daily) during the entire trial, including the collection periods. In the N balance study of (Geicsnek-Koltay et al. 2022), animals were fed with the calculated amount of 95% of *ad libitum* feed intake. Thus, they also observed elevated amounts of N intake and retention when feeding a diet comparable to the used diets in CP concentration. The results of the present trial and (Geicsnek-Koltay et al. 2022) indicate that *ad libitum* feeding, which is commonly used in practice, represents a limitation of balance method for the determination of nutrient retention in fattening pigs. However, retention determined in balance studies is used to obtain indirect information on nutrient accretion and chemical body composition of pigs (Walz and Pallauf 1989). Direct information on nutrient accretion and chemical body composition of the pigs of the present trial will be provided in a second publication.

## 5. Conclusion

This study provides updated data on the effects of *N*- and *P*-reduced feeding on fattening pigs. The results confirmed that a dietary N and P reduction lowers N and P excretion without impairing pigs' health, performance and N and P retention. Digestibility of organic matter, N-free extractives, starch and Ca was even higher in NPred – than CON-fed pigs. *N*- and *P*-reduced feeding in combination with other feeding strategies (e.g. phase feeding, addition of amino acids) remains an effective method of lowering the N and P release into the environment. Further research on the influence of additional feeding strategies will be needed to ensure an adequate nutrient supply of contemporary fattening pigs.

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