



Nitrogen and phosphorous content in the body of growing pigs in the Netherlands

Literature review and data analysis

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Samenvatting

Deze studie geeft een overzicht van beschikbare gegevens over het stikstof- en fosforgehalte in het lichaam van biggen en groeiende varkens. De resultaten duiden op een aanzienlijke variatie in het P-gehalte in het lichaam zonder duidelijke trend in de afgelopen decennia. Daarentegen bleek het gemiddelde N-gehalte in het lichaam geleidelijk te zijn toegenomen in de loop van de tijd. Op basis hiervan wordt een beperkte aanpassing voorgesteld van de referentiewaarden die worden gebruikt voor de jaarlijkse berekening van de uitscheiding van dierlijke mineralen door het Centraal Bureau voor de Statistiek.

Abstract

This study gives an overview of available data on nitrogen and phosphorus content in the body of piglets and growing pigs. The results indicated substantial variation in body P content without clear trend over the recent decades. In contrast, mean body N content appeared to have gradually increased over time. Based on the results, small changes are proposed in the reference values used for annual calculation of the mineral excretion of livestock by Statistics Netherlands.

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Foreword

Statistics Netherlands (CBS) annually calculates the manure production and excretion of nitrogen and phosphorus of the Dutch livestock. Manure production and mineral excretion are calculated by multiplying excretion factors in kilograms per animal per year by the number of animals in the Agricultural Census.

The excretion factors are set annually by the Werkgroep Uniformering berekening Mest- en mineralcijfers¹ (WUM), part of the expert committee Commissie Deskundigen Meststoffenwet (CDM). The purpose of the WUM is to establish annual excretion factors according to a uniform calculation methodology that are then used in the calculation of national mineral excretion and manure production. The results are used for evaluation of the Dutch manure policy and annual determination of the emission of pollutants to air, water and soil. The working group is composed of members from Wageningen Economic Research, Wageningen Livestock Research and CBS. The working group provide the basic data for the calculation of excretion factors.

This report presents the results of a study performed by Wageningen Livestock Research updating the available data on nitrogen and phosphorus content in the body of piglets and growing pigs. The authors thank the Ministry of LNVN for support and the members of the Werkgroep and the WUM improvement project for their valuable input in the study. 5.1.2.e (Wageningen Livestock Research) is gratefully thanked for his critical reading of the final draft of the report.

¹ Working Group on Uniform Calculation of Manure and Mineral Figures

Summary

The retention of nitrogen (N) and phosphorus (P) in the body of animals is a key-factor in the annual calculation of mineral excretion of livestock by Statistics Netherlands (CBS) based on the so-called WUM-model. To calculate the N and P deposited in body tissue this model needs actualised reference values for N and P content of pigs. Therefore this study collected and analysed available data on P and N content in the body of growing pigs and proposed an update of the reference values.

A literature search selected 16 studies for the period 2010-2024, corresponding to 159 observations (i.e. combination of dietary treatment and body weight range) indicating the body content of P or N of piglets and growing pigs. Pigs and experimental conditions used in these studies were considered representative for Dutch pig production. The data on body composition were obtained from slaughter of pigs, followed by sampling, grinding and chemical analysis of tissue samples in 11 of these studies. The five other studies used dual-energy X-ray absorptiometry (DXA) to analyse the body composition of pigs. The N content based on the slaughter and the DXA method were in good agreement, but the P content was consistently lower in studies with DXA than in studies with slaughter. Because of uncertainties in the assumptions used to estimate P content from bone mineral content determined with DXA, these studies were not included in the evaluation of the body P content.

Combined with the dataset available before start of this study, in total, 627 observations from 132 studies published since 1950 were analysed. The data were normalized for live body weight (LBW) and empty body weight (EBW) defined as the LBW of the animal without contents of the digestive tract and urine in the bladder (i.e. including blood and thoracic and abdominal organs). The observations were grouped in 4 periods: 1950-1969, 1970-1989, 1990-2009 and 2010-2024 in order to analyse their evolution over time. For each observation, the N and P content was calculated as g of N and P per kg of LBW and per kg of EBW. Body weight categories were based on the categories of the tables of Mestbeleid 2024 using weight limits for each category: i.e. Va 1 (newborn piglets): < 2 kg LBW; Va 2 (weaned piglets): 5 – 11.9 kg; Va 3 (nursery pigs): 19.5 - 31.5 kg; Va 4 (fattening pigs): 40 – 142 kg. Correlations among body N and P content and factors explaining differences (year of publication, net energy and P in diet, body weight, daily gain, fasting duration) were determined. Mean N and P content for each period were compared by analysis of variance. Allometric equations between body weight and N and P content were determined using the total data set for each period.

The year of publication of studies in the data set was positively correlated to daily gain, LBW and EBW, and N in LBW and EBW, and negatively correlated to P content in the diet and P content in EBW and LBW. Mean body N content appears to have gradually increased over time, but in slaughter pigs (Va-4) this effect is negated by the gradual increase in slaughter weight. Mean body P content varied substantially between periods, with an overall slightly decreasing trend. Based on mean results and allometric relationships, small changes in the reference values of body N and P content are proposed, as summarised in Table S1.

Table S1 Present and proposed reference values for nitrogen (N) and phosphorous (P) content (g/kg live body weight) in the body of pigs in different categories as adopted by Mestbeleid 2024.

Pig weight class	code	Present reference values			Proposed reference values		
		N, g/kg	P ₂ O ₅ , kg/kg	P, g/kg	N, g/kg	P ₂ O ₅ , kg/kg	P, g/kg
Newborn piglets	Va 1	18.7	0.0141	6.15	-	-	-
Weaned piglets, approx. 4 weeks of age	Va 2	24.4	0.0122	5.32	24.0	0.0118	5.17
Piglets of around 10 weeks of age (ca. 25 kg)	Va 3	24.8	0.0122	5.32	25.3	0.0120	5.25
Fattening pigs	Va 4	25.0	0.0123	5.37	25.0	0.0120	5.25

Samenvatting

Stikstof- en fosforgehalte in het lichaam van biggen en vleesvarkens in Nederland.

De vastlegging van stikstof (N) en fosfor (P) in het lichaam van landbouwhuisdieren is een belangrijke factor in de jaarlijkse berekening van de mineralenexcretie vanuit de veehouderij door het Centraal Bureau voor de Statistiek (CBS) op basis van het zogenaamde WUM-model. In deze studie zijn de beschikbare gegevens over het P- en N-gehalte in het lichaam van groeiende varkens aangevuld en geanalyseerd. Op basis hiervan wordt actualisatie van de forfaitaire gehalten voorgesteld.

In literatuuronderzoek werden 16 studies uit de periode 2010-2024 geselecteerd met in totaal 159 observaties (d.w.z. combinaties van voerbehandeling en lichaamsgewicht) van het P en/of N gehalte van biggen en groeiende varkens. Varkens en proefomstandigheden in deze studies werden als representatief beschouwd voor de Nederlandse varkenshouderij. De gegevens over de lichaamssamenstelling werden verkregen middels slachtstudies, gevolgd door homogeniseren en chemische analyse van lichaamssweefsel in 11 van deze studies. Vijf studies gebruikten dual-energy X-ray absorptiometry (DXA) om de lichaamssamenstelling te analyseren. De resultaten van de slachtmethode en de DXA-methode kwamen voor N goed overeen, maar het P-gehalte in het lichaam was consistent lager in studies met DXA dan in slachtstudies. Vanwege de onzekerheid in de aannames om het P-gehalte te bepalen met DXA op basis van het mineralen-gehalte in het skelet, werden deze studies niet gebruikt bij de evaluatie van het P-gehalte van het lichaam.

In combinatie met de reeds beschikbare dataset werden totaal 627 observaties geanalyseerd uit 132 studies die sinds 1950 gepubliceerd zijn. De gegevens werden genormaliseerd voor levend lichaamsgewicht (LBW), leeg lichaamsgewicht (EBW) gedefinieerd als het LBW van het dier zonder de inhoud van het darmkanaal en urine in de blaas, dus inclusief bloed en organen. De observaties werden gegroepeerd in 4 periodes: 1950-1969, 1970-1989, 1990-2009 en 2010-2024 om de ontwikkeling in de tijd te analyseren. Voor elke observatie werd het N- en P-gehalte berekend als g N en P per kg LBW en per kg EBW. De gewichtscategorieën werden afgestemd op de categorieën in de tabellen van Mestbeleid 2024 met gewichtslimieten voor elke categorie: Va 1 (pasgeboren biggen): < 2 kg LBW; Va 2 (gespeende biggen): 5 - 11,9 kg; Va 3 (biggen van ongeveer 10 weken): 19,5 - 31,5 kg; Va 4 (vleesvarkens): 40 - 142 kg. Correlaties tussen het N- en P-gehalte van het lichaam en factoren die verschillen verklaren (netto energie en P in de voeders, lichaamsgewicht, dagelijkse groei, periode van vasten voor slacht) werden getest. De gemiddelden voor elke periode werden vergeleken door middel van variantieanalyse. Allometrische relaties werden bepaald op basis van de totale dataset voor elke periode. Het jaar van publicatie van de studies in de dataset was positief gecorreleerd met groei, LBW, EBW, and N in LBW en EBW, en negatief gecorreleerd met P-gehalte in het voer en P in LBW en EBW. Het gemiddelde N-gehalte in de varkens bleek in de loop van de tijd geleidelijk te zijn toegenomen, maar bij vleesvarkens (Va-4) wordt deze stijging teniet gedaan door de geleidelijke toename van het slachtgewicht. Het gemiddeld P-gehalte varieerde aanzienlijk tussen perioden, met een geleidelijke daling in de tijd. Gebaseerd op de gemiddelde resultaten en allometrische relaties, worden kleine aanpassingen voorgesteld in de referentiewaarden van het N- en P-gehalte van het lichaam, zoals samengevat in tabel S2.

Table S2 *Huidige en voorgestelde forfaitaire gehalten (g/kg levend gewicht) stikstof (N) en fosfor (P) in het lichaam van varkens van verschillende categorieën onderscheiden in het Mestbeleid 2024.*

Categorie varkens	code	Huidige forfaitaire waarden			Voorgestelde forfaitaire waarden		
		N, g/kg	P ₂ O ₅ , kg/kg	P, g/kg	N, g/kg	P ₂ O ₅ , kg/kg	P, g/kg
Pasgeboren biggen	Va 1	18.7	0.0141	6.15	-	-	-
Gespeende biggen, ongeveer 4 weken oud	Va 2	24.4	0.0122	5.32	24.0	0.0118	5.17
Biggen van ongeveer 10 weken (ca. 25 kg)	Va 3	24.8	0.0122	5.32	25.3	0.0120	5.25
Vleesvarkens	Va 4	25.0	0.0123	5.37	25.0	0.0120	5.25

1 Introduction

The excretion of total nitrogen (N) and phosphorous (P) in manure of farm animals, and of N in urine that can potentially be converted into ammonia (TAN), is annually calculated by the CBS (Statistics Netherlands) based on the so-called WUM-model. This model comprises methodology, equations and assumptions developed and adopted by the Working group on Uniformity of Manure and mineral data (WUM). The calculated mineral excretion is essential information to evaluate Dutch and European manure policy, whereas the TAN excretion is the basis to calculate ammonia emission from the animal production sector. Furthermore, N and P excretion calculated according to the WUM-model are used to determine the gaseous N losses until manure is transported and removed from individual farms as described by [5.1.2.e](#) and [5.1.2.e](#) (2019). The validity of the WUM model is crucial, since aforementioned results are the basis for monitoring the progress in emission reduction, and have important consequences for determining governmental decisions on regulations to protect the environment. Therefore a project (BO-43-101-044-WLR Verbetering excretiemodellen) is being conducted to improve the substantiation, transparency and quantification of the precision of calculating N, P and TAN excretion according to the WUM method. As start of this project an analysis was conducted to determine the sensitivity of the calculated mineral excretion to variation in factors used in the WUM-model (Veraart et al., 2022). For growing pigs, the estimate of N and P retained in the body of the animals was identified as a factor with high influence on the calculated mineral excretion and given priority for further evaluation. The latest update of the factors used for body composition of pigs was made in 2010 and a quick scan indicated that new studies were published since then. Therefore, the study described in this report was conducted to determine whether the N and P content in the body of growing pigs, as adopted in the WUM-model was in agreement with recent literature, and to give recommendations for an update when appropriate.

The excretion of N and P of growing pigs is determined according to the balance method: excreted N and P is calculated as N and P intake via the feed minus N and P retained in the body. Retention in the body is calculated as total N and P in the body at the end of the growing period, generally at slaughter, minus total N and P at the start of the growing period. Total N and P in the body is calculated as body weight multiplied by the reference N and P content per kg body weight in the specific phase of life. Table 5 of 'Mestbeleid 2024 Tabellen' of January 2024 gives actual reference values of N and P content in animals (Table 1). This table is used by individual pig farmers to calculate the N and P excretion of their animals and by CBS for the calculation of the total national N and P excretion of pigs. The amount of N and P in animals is different for each animal category. For slaughtered pigs for which carcass weight is known, the carcass weight is converted to the live body weight in order to calculate total N and P in the body. Only when the body weight is unknown (e.g. when an animal is culled or moved within a farm), it is allowed to use the table value per animal of the relevant category rather than the content per kg body weight, as an estimate of total content per animal.

Table 1 Part of Table 5 of Mestbeleid 2024 with nitrogen and phosphate content per kg body weight for different categories of pigs. for each category of pigs².

Diersoorten	Diercategorie-code	Per kg lichaams gewicht		Per dier	
		Kg stikstof	Kg fosfaat	Kg stikstof	Kg fosfaat
Varken					
Pasgeboren biggen	Va 1	0,0187	0,0141	0,03	0,02
Gespeende biggen, ongeveer 4 weken oud	Va 2	0,0244	0,0122	0,18	0,09
Biggen van ongeveer 10 weken (ca. 25 kg)	Va 3	0,0248	0,0122	0,65	0,32
Vleesvarkens	Va 4	0,0250	0,0123	2,85	1,40
Fokzeugen	Va 5	0,0250	0,0123	5,13	2,51
Opfokzeugen/beren van ongeveer 7 maanden	Va 6	0,0249	0,0132	3,11	1,65
Fokberen ouder dan 7 maanden	Va 7	0,0250	0,0123	8,13	3,98
Slachtzeugen	Va 8	0,0250	0,0123	5,13	2,51

In this table, phosphorous is expressed as phosphate (P₂O₅) which is often used in agriculture or industry as proxy value for all the phosphorus oxides in a material. Conversion from P₂O₅ to P is done with the factor 2.29³. Results are shown in 5.1.2.e It was the aim of this study to evaluate in particular the values for N and P content in growing finishing (fattening) pigs of category Va 4 as recommended by Veraart et al. (2022).

Table 2 Nitrogen and phosphorous content (g/kg body weight) in the body of pigs in different categories as adopted by Mestbeleid 2024.

Pig weight class	code	N, g/kg	P ₂ O ₅ , kg/kg	P, g/kg
Newborn piglets	Va 1	18.7	0.0141	6.15
Weaned piglets, approx. 4 weeks of age	Va 2	24.4	0.0122	5.32
Piglets of around 10 weeks of age (ca. 25 kg)	Va 3	24.8	0.0122	5.32
Fattening pigs	Va 4	25.0	0.0123	5.37
Breeding sows	Va 5	25.0	0.0123	5.37
Replacement gilts/boars around 7 months of age	Va 6	24.9	0.0132	5.76
Breeding boars older than 7 months	Va 7	25.0	0.0123	5.37
Sows for slaughter	Va 8	25.0	0.0123	5.37

² From Mestbeleid 2024 Tabellen. Tabel 5: Stikstof en fosfaat in dieren

³ The P₂O₅ content allows convenient comparison of the phosphorous content of different compounds (e.g. fertilizers). Atomic masses of oxygen: 16.00 and phosphorus: 30.97. Molar mass of P₂O₅ = 30.97×2+16.00×5 = 141.94 g/mol. Conversion ratio in phosphorus : 141.94/(2×30.97)=2.29.

2 Material and Methods

2.1 Collection of data

An existing database of Wageningen Livestock Research on body composition and retention of P and N in pigs has been extended. This database was based on studies with new-born and growing-finishing pigs published between 1947 and 2012. For each of these studies, animals were slaughtered and tissues were sampled, ground and analysed for N and/or P content. The analytical results, reported as N and P contents of empty body weight (EBW) and/or live body weight (LBW), were related to experimental treatments and/or age or sex groups of animals, further called observations. For these observations the mean initial or intermediate weights of the animals, and LBW and/or EBW at slaughter were also collected. Dry matter (DM), fat and ash contents of the body were reported for most of the studies. The dietary P content was available for most of the studies. Detailed protocols and methods of the studies were not included in the database.

Table 3 *Number of studies and observations for nitrogen (N) and/or phosphorous (P) content in pigs bodies per period, used to derive standard body N and P contents of pigs to calculate N and P excretion from pig farms.*

Period	1947-1969	1970-1989	1990-2009	2010-2024	Total
Studies, n	18	46	52	16	132
Observations, n	64	190	215	159	628

A new literature search was undertaken for this study using several tools (MyLibrary, PubMed, Google, Google Scholar, Research Gate) using search terms including body composition AND (mineral OR nitrogen OR phosphorus) AND (pigs OR sow OR swine), for recent studies (since 2010) peer-reviewed and published in English, Dutch or French in scientific journals, as well as conferences, dissertations or reports. For the inclusion in the dataset, all papers should have a clear description of animals and materials and methods, and include either LBW or EBW or both, at the day of measurement of body composition of pigs (Table 3). A total of 16 recent studies corresponding to 159 observations (i.e. a combination of experimental dietary treatment with identified sex or physiological group) of piglets or fattening pigs were selected⁴⁵. These studies were published between 2008 and 2023 and were undertaken in The Netherlands, Switzerland, Canada, Australia and USA. A brief description of the new references is included at the end of this document in [5.1.2.e](#). Only observations corresponding to dietary treatments classified by the authors as providing quantities of protein, amino acids or minerals (P) covering at least 100% of the animals' requirements were selected.

The data on body composition were obtained from slaughter, followed by sampling, grinding and chemical analysis of tissue samples in 11 of the new studies. Among these, seven studies (Columbus et al., 2008, 2010; [5.1.2.e](#) et al., 2013, 2018; Hulshof et al., 2016; Ruiz-Ascacibar et al., 2019; [5.1.2.e](#) et al., 2021) provided results for both N and P content, three on N content only (Arthur et al., 2011; Boddicker et al., 2011a, 2011b; Totafurno et al., 2019, 2020), and one on P content only (Peters et al., 2010). The five other studies (Andretta et al., 2014, 2016; Remus et al., 2019; Lautrou et al., 2021; Bee et al., 2023) used dual-energy X-ray absorptiometry (DXA) to analyse the body composition of pigs. DXA scans use spectral images based on the difference of absorption between two X-ray beams to measure body composition, fat content and bone mineral content. Two of these studies presented data on both N and P content of the pigs (Andretta et al., 2014, 2016), two on N content (Remus et al., 2019; Bee et al., 2023) and there was one study reporting only P content (Lautrou et al., 2021). The dietary crude protein (CP) content was reported in all studies measuring N content of pigs except one study (Remus et al., 2019) in which a precision feeding design was based on high and low protein diets mixed in changing proportions according to the individual requirements of the pigs.

⁴ Body composition of sows was recently reported in studies of Peters (2010), Dourmad et al. (2021), Heurtault et al. (2023a, b).

⁵ The observations since 2010 were calculated from 2 to 37 individual pigs each (mean: 9.9 pigs per observation)

The total P content of the diets was available for all studies reporting the P retention of animals. Overall, 627 observations from 132 publications were collected (Table 3)⁶. The list of the references is included at the end of this document.

2.2 Evaluation of body composition

2.2.1 Body weights

The empty body weight (EBW) was defined as the BW of the animal without contents of the digestive tract and urine in the bladder, i.e. including blood and thoracic and abdominal organs. The content of the bladder was considered as negligible. However, as EBW was reported without blood in the recent studies of Columbus et al. (2008, 2010), the blood volume in the body of slaughtered pigs in this study was estimated using the values published by Vaissaire (1982)⁷. Additionally, EBW was not directly reported in seven recent studies (Arthur et al., 2011; Andretta et al., 2014, 2016; Remus et al., 2019; Lautrou et al., 2021; Bee et al., 2023). For these studies, EBW was calculated from LBW using the following equation established by 5.1.2.e and Blok (2017) from a meta-analysis of 458 groups of pigs:

$$\text{EBW, kg} = 0.0002 \times \text{LBW}^2 + 0.9226 \times \text{LBW} + 0.1484, \text{ kg. } R^2=0.99.$$

LBW was calculated from EBW in the study by 5.1.2.e et al. (2021) using the reverse equation of 5.1.2.e and Blok (2017).

2.2.2 Methodologies

For studies using the slaughter method, sampling and chemical analysis, after incineration of samples to determine ash (inorganic matter), and solubilization with nitric acid, P and minerals were analysed using spectrometry or colorimetry. Nitrogen was determined using the Kjeldahl method in a digestion and distillation system. Crude protein was calculated by multiplying the N content by 6.25.

Authors using DXA, have converted DXA measurements of body lean and fat mass into the chemical equivalents of protein and lipid, as proposed by Pomar and Rivest (1996). In all studies using DXA (Andretta et al., 2014, 2016; Remus et al., 2019; Lautrou et al., 2021; Bee et al., 2023), serial DXA measurements were conducted in live pigs. No information was available about the fasting procedure in the studies of Andretta et al. (2016), Remus et al. (2019) and Lautrou et al. (2021) whereas Andretta et al. (2014)⁸ and Bee et al. (2023) reported the fasting time. Additionally, recent studies based on DXA measurements used an approximation for the estimation of the body P content. In these studies, Lautrou et al. (2021) and Andretta et al. (2014, 2016) calculated the total body P assuming that 18% of bone mineral content was P and that DXA bone mineral content represented 80% of total body P (Merkatoris et al., 2012). Potential consequences of these assumptions are addressed in paragraph 3.2.1.

2.2.3 Normalization of P and N contents

For studies of Columbus et al. (2008, 2010), authors measured and reported the protein content on the basis of the EBW without blood. In the study reported by Boddicker et al. (2011a,b), authors reported the protein content on the basis of the carcass weight. As viscera were weighed separately, the quantity of protein was estimated using the viscera composition published by Totafurno (2018) and Totafurno et al. (2019, 2020)⁹. For these studies, corrections were made to take into account the protein content of blood¹⁰, whereas P content of blood was neglected.

To estimate the total content of N and P of the pigs when they leave the farm (i.e. on LBW basis), the gut fill must be taken into account. However, only a few of the recent studies in the dataset (5.1.2.e et al., 2013, 2018; Hulshof et al., 2016; Totafurno et al., 2019, 2020) weighed the gut fill or reported the N and P content in the digesta of the animals (5.1.2.e et al., 2013).

⁶ The observations of total data set were calculated from 1 to 214 individual pigs each (mean: 11.2 pigs per observation)

⁷ Blood volume: 6.0%, 4.0% and 3.2% of carcass weight in nursery, growing and finishing pigs, respectively (Vaissaire, 1982)

⁸ Andretta et al. (2014) indicated that they applied a 0.21% reduction to LBW per hour of fasting to eliminate the influence of the fasting duration (16 hours). This final LBW was kept in the study data set.

⁹ Protein composition of viscera : 13.9% in growing pigs; 14.7% in finishing pigs (Totafurno, 2018)

¹⁰ Protein composition of blood : 16% (adapted from Walker, 1977).

Therefore, in our report, the gut fill quantity was estimated as the difference between LBW and EBW. When not available, the N and P content of the gut fill for the recent studies of the period 2010-2024 was estimated on the basis of the following assumptions. As a fasting time between last meal and slaughter was applied for most of the studies, we assumed that the stomach of the pigs was almost empty. It was assumed that the gut fill had a mean DM content of 25%. Subsequently, it was assumed that 40% of the dietary CP content on as fed-basis was undigested, to calculate the final CP content of the gut fill. For the study reported by Remus et al. (2019), the CP content was calculated as 10% of the DM of the gut fill.

The P content of the gut fill was estimated on the basis of the undigestible dietary P content (i.e. total P – digestible P) when this information was available from the publication (Andretta et al., 2014, 2016; 5.1.2.e et al., 2013, 2018; Ruiz-Ascacibar et al., 2019; Lautrou et al., 2021). For other studies not reporting the digestible P content (DigP) of the diet (Columbus et al., 2008, 2010; 5.1.2.e et al., 2021), a coefficient of 50% of the dietary total P content (as-fed basis) was applied to calculate the P content of the gut fill (with 25% DM content).

For the suckling piglets of the study reported by Peters et al. (2010), the gut fill content in CP and P was estimated from sow milk composition as indicated by Renaudeau and Noblet (2001) and Perrin et al. (1955). Finally, as carcass weight, gut fill weight and the dietary protein content could not be precisely derived from the publications of the DXA study of Remus et al. (2019), the N and protein contents were only established for LBW.

2.3 Calculations and data analysis

For each group of animals, the N and P content was calculated as g of N and P per kg of LBW (N_LW, P_LW) and per kg of EBW (N_EBW, P_EBW).

Each group was allocated to one of the animal categories (Diercategorie) of the tables of Mestbeleid 2024. As no indication of the minimum and maximum weight of each animal category was mentioned in the tables of Mestbeleid 2024, a range of weight limits was applied for each category as follows:

Va 1, newborn piglets:	< 2 kg LBW
Va 2, weaned piglets:	5 – 11.9 kg LBW
Va 3, nursery pigs:	19.5 – 31.5 kg LBW
Va 4, fattening pigs:	40 – 142 kg LBW

Based on sex of the pigs, each group was allocated to one of five categories: entire male (M), castrated males (C), females (F), mix of entire males and females (M+F), mix of castrated males and females (C+F). Groups without specification of sex were coded as unknown in an additional 6th category.

Daily gain was reported as the mean ADG for the total period or for the last period of the study before slaughter for long lasting studies with several periods. When P content of the diet was differentiated for a sequence of feeding phases, a mean value was applied.

On the basis of the year of publication, four periods were distinguished: 1950-1969, 1970-1989, 1990-2009, 2010-2024. A study reported in the thesis of Columbus (2008) was allocated to the 2010-2024 period, as it was part of a project of several trials published later by Columbus et al. (2010).

At first, a graphical analysis was made with Excel in order to find relations among parameters and factors explaining differences among groups of studies. Correlations among parameters were tested using the correlation procedure of SAS (Proc CORR, SAS 9.4, SAS Inst., Cary, NC). Thereafter variance analysis among the periods of publication of the studies was performed using the GLM procedure (Proc GLM of SAS). The observation was considered as the experimental unit. Data analysis was performed for the whole data set and subsequently by weight category with the main fixed effect of period and random effects of study within period and sex. Depending on the parameter, LBW or EBW was added as covariate in order to improve the statistical model. The Tukey test was used for comparison of means between periods. Within each period, observations of the data set were used to estimate allometric equations as supplementary material (See Appendix 3). After logarithmic transformation, linear and quadratic equations were determined to relate total body N and P mass to LBW.

3 Results

3.1 Description of the database

An overview of the number of observations per period and parameter for the total database is shown in Table 4. Information on pig body weight (LBW and EBW) and gut fill content was available for all 627 observations of the final database, whereas body composition was available or calculated for N in 559 observations (N_EBW and N_LW) and for P in 311 observations (P_EBW and P_LW). Total body ash, daily gain and hours of fasting before slaughter were calculated for 40-70% of observations. Information on diet composition was collected or calculated for total and digestible P (60 and 57% of observations, respectively, and net energy (NE) content (54%). Besides that, dietary CP (n=113), ash (n=74), total (n=70) and digestible lysine (n=58) was collected only for the new studies of the 2010-2023 period. Mean, standard deviation and minimum and maximum values for each parameter are displayed in 5.1.2.e

Table 4 Number of observations for diet composition, body composition and nitrogen (N) and phosphorous (P) body content in pig studies of the data set by period.

	1950-1969	1970-1989	1990-2009	2010-2024	Total
Number of observations, n	64	190	215	158	627
P_diet, g/kg	18	123	140	96	377
DigP_diet, g/kg	18	123	140	77	358
NE, MJ/kg	18	120	138	66	342
Daily gain, g/d	50	176	161	71	458
Fasting, h	30	72	101	88	291
LBW, kg	64	190	215	158	627
EBW, kg	64	190	215	158	627
Gut fill, kg	64	190	215	158	627
Ash, g	37	175	156	69	437
N_LW, g/kg	50	190	190	129	559
P_LW, g/kg	34	66	112	99	311
N_EBW, g/kg	50	190	190	105	535
P_EBW, g/kg	34	66	112	99	311

Abbreviations: P_diet: total phosphorus content of the diet; DigP_diet: digestible phosphorus content of the diet; NE: net energy; LBW: live body weight; EBW: empty body weight; N_LW: nitrogen content of live body weight; P_LW: phosphorus content of live body weight; N_EBW: nitrogen content of empty body weight; P_EBW: phosphorus content of empty body weight.

Table 5 Descriptive statistics of parameters in the data set.

Parameter	N	Mean	Std Dev	Minimum	Maximum	Label
Year	627	1994	17	1947	2023	Year
P_diet, g/kg	377	6.27	1.59	3.20	14.05	P_diet
DigP_diet, g/kg	358	3.38	1.20	1.39	10.06	DigP
NE, MJ/kg	342	9.98	0.8	7.1	16.4	NE
Daily gain, g/d	458	620	309	68	1360	ADG
Fasting, h	291	9.4	10.6	0.0	48.0	Fasting
LBW, kg	627	59.5	44.0	1.0	208.1	LBW
EBW, kg	627	56.1	41.9	0.9	199.8	EBW
Gut fill, kg	627	3.4	2.7	-0.1	18.8	Gut fill
Ash, g	437	1647	1294	31.4	5900	Ash
N_LW, g/kg	559	24.0	2.4	16.5	30.0	N_LW
P_LW, g/kg	311	4.81	0.68	3.00	6.79	P_LW
N_EBW, g/kg	535	25.5	2.4	18.0	31.9	N_EBW
P_EBW, g/kg	311	5.07	0.73	3.21	6.79	P_EBW

Abbreviations of parameters: See Table 4.

Correlations among parameters are displayed in [5.1.2.e](#). As expected, live and empty body weight and gut fill were strongly correlated. Equations expressing EBW relative to LBW were used for the calculation of the missing values, whereas gut fill was the difference between EBW and LBW. Total amount of body ash and daily gain were strongly correlated to EBW and LBW. The year of publication of studies was positively correlated to daily gain, LBW, EBW, N_EBW and N_LW and negatively correlated to total and digestible P contents in the diets and P content in EBW and LBW. Daily gain correlated positively with body N content (N_EBW and N_LW) but negatively with body P content (P_EBW and P_LW). Body P content was positively correlated with the total and digestible P contents of the diet. The dietary NE content correlated negatively with body P content but not with N body content. Phosphorous and N contents in live- and empty- body were not correlated to each other.

Table 6 Pearson correlation coefficients among parameters of the database with nitrogen and phosphorous content in the body of pigs (n=634 observations).

	Year	P_diet	DigP	NE	ADG	Fasting	LBW	EBW	Gut fill	Ash	N_LW	P_LW	N_EBW	P_EBW
Year	1.00													
P														
n	627													
P_diet	-0.41	1.00												
P	<.0001													
n	377	377												
DigP	-0.43	0.89	1.00											
P	<.0001	<.0001												
n	358	354	358											
NE	0.05	0.06	0.22	1.00										
P	0.38	0.25	<.0001											
n	342	331	317	342										
ADG	0.52	-0.32	-0.38	-0.09	1.00									
P	<.0001	<.0001	<.0001	0.15										
n	458	297	294	280	458									
Fasting	0.04	-0.29	-0.22	-0.35	0.15	1.00								
P	0.46	0.0001	0.0047	<.0001	0.0305									
n	291	165	159	160	202	291								
LBW	0.23	-0.23	-0.32	-0.15	0.79	0.18	1.00							
P	<.0001	<.0001	<.0001	0.0045	<.0001	0.0021								
n	627	377	358	342	458	291	627							
EBW	0.24	-0.24	-0.32	-0.15	0.79	0.17	1.00	1.00						
P	<.0001	<.0001	<.0001	0.0053	<.0001	0.0027	<.0001							
n	627	377	358	342	458	291	627	627						
Gut fill	0.09	-0.07	-0.17	-0.14	0.67	0.21	0.80	0.78	1.00					
P	0.0196	0.16	0.0010	0.0090	<.0001	0.0003	<.0001	<.0001						
n	627	377	358	342	458	291	627	627	627					
Ash	0.21	-0.17	-0.22	-0.14	0.75	0.05	0.97	0.98	0.70	1.00				
P	<.0001	0.007	0.0003	0.026	<.0001	0.47	<.0001	<.0001	<.0001					
n	437	262	261	265	328	226	427	437	437	437				
N_LW	0.33	-0.06	0.01	-0.07	0.27	0.09	0.03	0.04	-0.12	0.12	1.00			
P	<.0001	0.27	0.87	0.21	<.0001	0.14	0.51	0.38	0.0041	0.0151				
n	559	327	311	308	423	275	559	559	559	423	559			
P_LW	-0.20	0.35	0.39	-0.30	-0.19	0.18	-0.07	-0.07	-0.12	0.15	0.14	1.00		
P	0.0003	<.0001	<.0001	<.0001	0.0042	0.0384	0.22	0.24	0.0422	0.0396	0.0261			
n	311	240	224	194	224	133	311	311	311	200	249	311		
N_EBW	0.28	-0.02	0.05	-0.09	0.28	0.17	0.02	0.02	0.01	0.08	0.95	0.10	1.00	
P	<.0001	0.68	0.43	0.11	<.0001	0.0061	0.64	0.63	0.88	0.11	<.0001	0.09		
n	535	327	311	308	411	275	535	535	535	423	535	249	535	
P_EBW	-0.25	0.37	0.40	-0.32	-0.23	0.11	-0.09	-0.09	-0.07	0.13	0.11	0.98	0.11	1.00
P	<.0001	<.0001	<.0001	<.0001	0.0007	0.19	0.12	0.12	0.21	0.0762	0.0944	<.0001	0.0829	
n	311	240	224	194	224	133	311	311	311	200	249	311	249	311

Values are Pearson correlation coefficients. P value calculated from Proc corr analysis of SAS. n : number of observations for each correlation. Darker colours indicate larger positive (grey) or negative (blue) correlation coefficients

3.2 Body phosphorous content

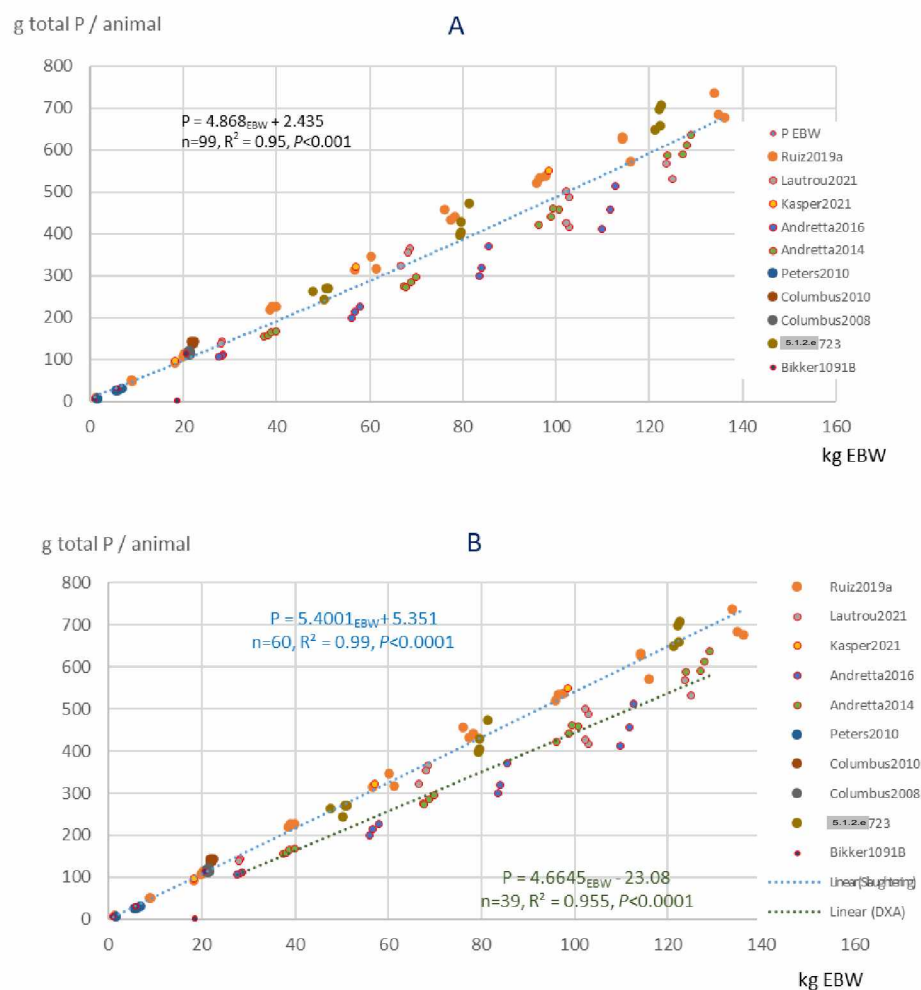
3.2.1 Influence of the measurement methodology

In the 2010-2024 period, five of the reviewed studies used DXA scanning of the (live) animal to evaluate the body composition of the pigs (See paragraphs Collection of data and Measurement'). Compared to studies of the same period using the slaughter technique, differences were observed for LBW, EBW and gut fill with pigs of DXA studies being heavier (Table 7). The DXA technique facilitates scanning of heavier pigs whereas the dataset of slaughter studies comprised a number of studies with piglets. As a result, the total body content of P was higher in the DXA dataset. Nonetheless, the P content expressed per kg of LBW or EBW was lower with DXA.

Table 7 Body characteristics and diet composition in studies published in the 2010-2024 period using DXA or slaughter methods to determine body phosphorous content, for all weight categories.

	DXA	Slaughter	RMSE	P-value
Studies, n	3	7		
Body composition				
Observations, n	39	60		
EBW, kg	79.4 (± 33.3)	51.1 (± 43.7)	34.5	< 0.001
LBW, kg	84.1 (± 34.9)	53.2 (± 45.1)	35.9	< 0.001
Gut fill, kg	4.7 (± 1.6)	2.1 (± 1.6)	1.4	< 0.001
Total live body P, g	347 (±159)	278 (±235)	176	< 0.001
P_EBW, g/kg	4.21 (± 0.50)	5.44 (± 0.51)	0.34	< 0.001
P_LW, g/kg	4.07 (± 0.44)	5.24 (± 0.50)	0.35	< 0.001
Diet composition				
Observations, n	39	51*/35**		
P_diet, g/kg	4.40 (±1.08)	5.18 (±1.10)	0.80	< 0.001
Dig P, g/kg	2.25 (±0.73)	2.54 (±0.51)	0.52	< 0.001

Values in the table are presented as means and root mean square error. *: n= 51 observations with P_diet value; **: n = 35 observations with DigP value. P value from analysis of variance including the fixed effect of measurement method.



Parameters and P value of the equations from regression analysis using the Proc reg of SAS

Figure 1 Total body P content in relation to EBW for all studies of the 2010-2024 period (A) and with separate linear regression equations for slaughter and DXA studies (B).

For both the DXA and slaughter method, the total body P content increased with LBW. The three DXA studies (Andretta et al., 2014, 2016; Lautrou et al., 2021) reported a lower P content than the studies using the slaughter method (Figure 1, Table 7). As a result, a difference of approximately 1.2 g per kg was observed between the two methods. Because of the uncertainties and assumptions involved in the calculation of body P content with DXA, e.g. regarding the P content in bone and the relative proportion of body P in bone, the whole body analysis of P content after slaughter is regarded as a more reliable method. Therefore, the following analysis of the body P composition of pigs is based on data obtained with only the slaughter method.

3.2.2 Influence of dietary P content on body P content

The total (Figure 2a) and digestible P (DigP) content (Figure 2b) in the diets of studies published since 1990 was in general somewhat lower than for the 1970-1989 period. This was also reflected in a lower body P content of pigs). Studies from the periods 1990-2009 and 2010-2024 showed that body P content increased with increasing dietary digestible P until a plateau of 5-5.5 g/kg EBW for a DigP content above 3.0 g/kg diet (Figure 2b). Overall, the body P content in studies published over the period 1990-2010 was somewhat lower than in other periods. Results in 5.1.2.e illustrate that this may be related to specific studies.

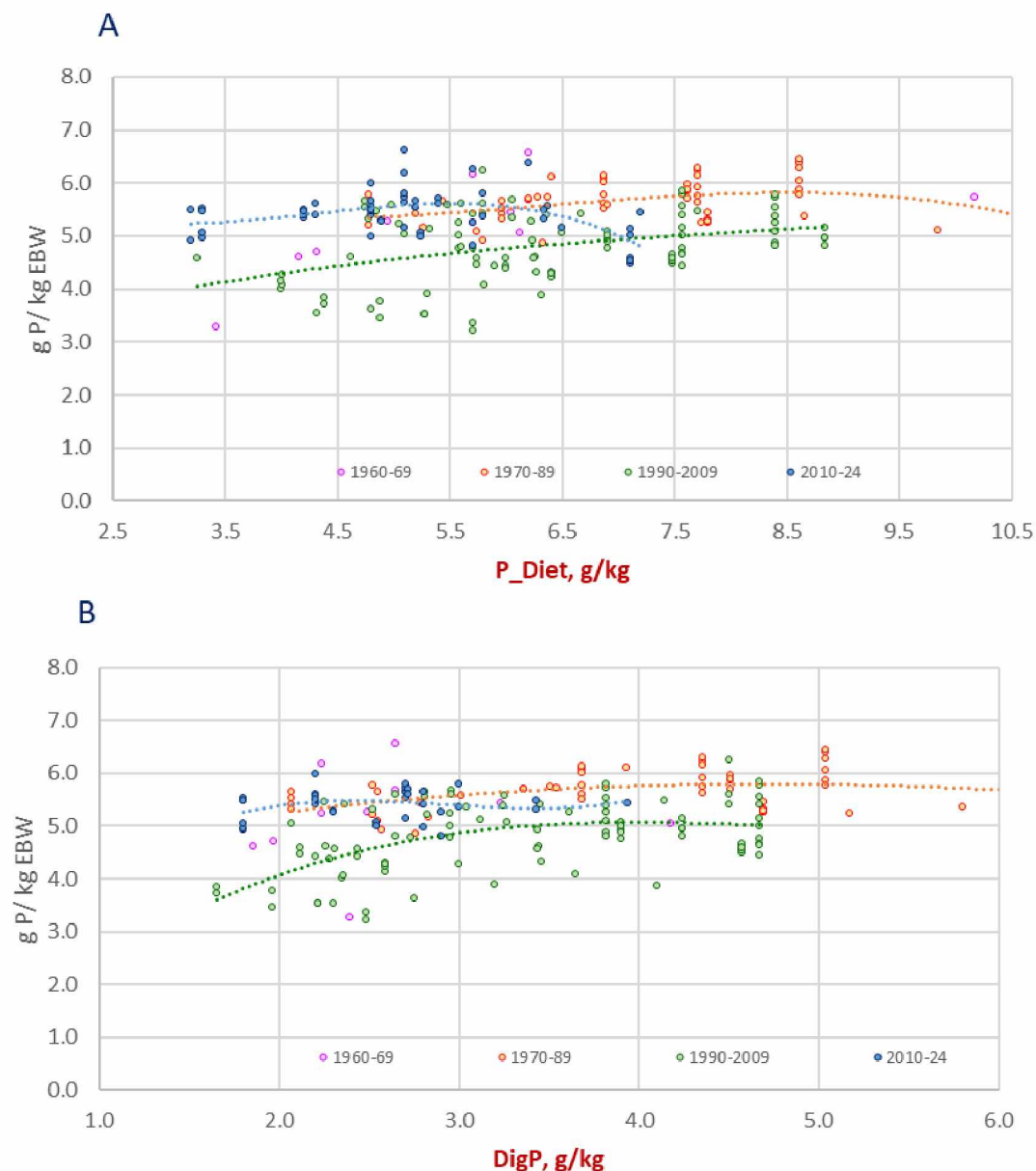


Figure 2 Influence of dietary total P (A) and digestible P (DigP) (B) content on the P content in the empty body (EBW) per period, based on the slaughter method and body analysis for pigs of all weight categories.

3.2.3 Data analysis

3.2.3.1 Analysis of the whole dataset

Because of the differences between the slaughter method and DXA for the 2010-2024 period, the analysis was conducted using only results obtained with the slaughter method (Table 8). From the total dataset with 627 observations, 272 observations included phosphorus content (P_EBW and P_LW values) obtained with the slaughter method. Around 56% of observations belonged to the category with growing finishing pigs (Va 4), whereas categories with weaned pigs (Va 2) and nursery pigs (Va 3) accounted for 13% and 16%, respectively (Table 8). It should be noted that body weight differed among the periods, as it appeared that average EBW and LBW were lower for the 1950-69 period and higher for the 1990-2009 period ($P < 0.05$; Table 9).

Table 8 Number of observations with P content in empty body (P_EBW) and live weight (P_LW) obtained with the slaughter method in categories newborn, weaned, nursery and growing finishing (GF) pigs.

Code	Va 1 Newborn	Va 2 Weaned	Va 3 Nursery	Va4 GF pigs	others	Total
Range, kg LBW	1.0-1.8	5 -11.7	19.6-30.8	40-141.2		
P_EBW, P_LW, n	8	35	43	154	32	272

Observations for the 2010-2024 period did not differ in mean body weight from the previous 1990-2009 period (Table 9). The mean body P content (P_EBW and P_LW) did not differ from the values obtained for the periods 1950-69 and 1970-89 and were higher than those obtained for the 1990-2009 period (Table 9, Figure 3).

Table 9 Body weight and body phosphorus content in empty (P_EBW) and live (P_LW) body weight calculated per period for all weight categories with the slaughter method.

Period	1950-1969	1970-1989	1990-2009	2010-2024	RMSE	Stat	R ²
n	34	66	112	60			
EBW, kg	28.1 ^a	69.9 ^b	52.6 ^c	51.1 ^c	28.6	P***, SP***	0.56
LBW, kg	29.7 ^a	74.6 ^b	55.6 ^c	53.2 ^c	29.8	P***, SP***	0.56
Gut fill, kg	1.6 ^a	4.7 ^b	3.0 ^c	2.1 ^a	1.48	P***, SP***	0.66
P_EBW, g/kg	5.30 ^a	5.53 ^{ab}	4.84 ^c	5.44 ^{ab}	0.37	P***, SP***, LBW***	0.75
P_LW, g/kg	5.03 ^a	5.17 ^{ab}	4.56 ^c	5.24 ^{ab}	0.36	P***, SP***, LBW*	0.73

Values in the table are presented as means and root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex. LBW is added as covariable for P_EBW and P_LW. P-value: ns: > 0.05 , * < 0.05 , ** < 0.01 , *** < 0.001 .

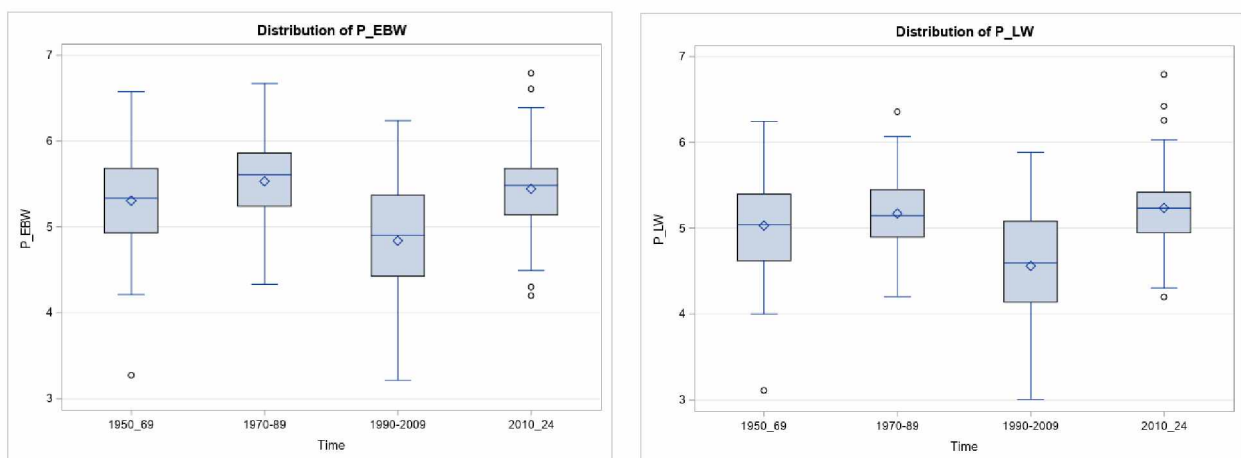


Figure 3 Distribution of mean phosphorus content in empty body (P_EBW) and live weight (P_LW) per period for all weight categories combined, based on the slaughter method (272 observations). (Each box plot represents summary statistics and outlier values of the P content per period. The height of the box represents the interquartile range (IQR; the distance between the 25th and 75th percentiles).

The symbol and the horizontal line in the box interior represent the mean and median value, respectively. The vertical lines (or whiskers) issuing from the box extend to the group minimum and maximum values. Outlier values (upper 1.5 IQR above 75th percentile or lower 1.5 IQR below 25th percentile) are plotted as separate points beyond the whiskers of the box.)

The relation of P content in the empty body and EBW of the pigs is shown for each period in 5.1.2.e This figure shows that, within each period, the body weight had limited effect on the P_EBW. For the periods 1990-2009 and 2010-2024, P_EBW values are displayed per study in 5.1.2.e Results displayed in Figures 3 and 4, and in the appendix indicate that in the period 1990-2009 some studies (Ketaren et al, 1993a,b,c; Hendricks and Moughan, 1993; Pettey et al, 2004; Wiseman et al, 2009) with low P_EBW had a clear lowering influence on the mean P_EBW. Figure 2 suggests that observations of 1990-2009 studies may have lower body P-content partly because of a low dietary P-content.

Parameters and P value of the equations from regression analysis using the Proc reg of SAS

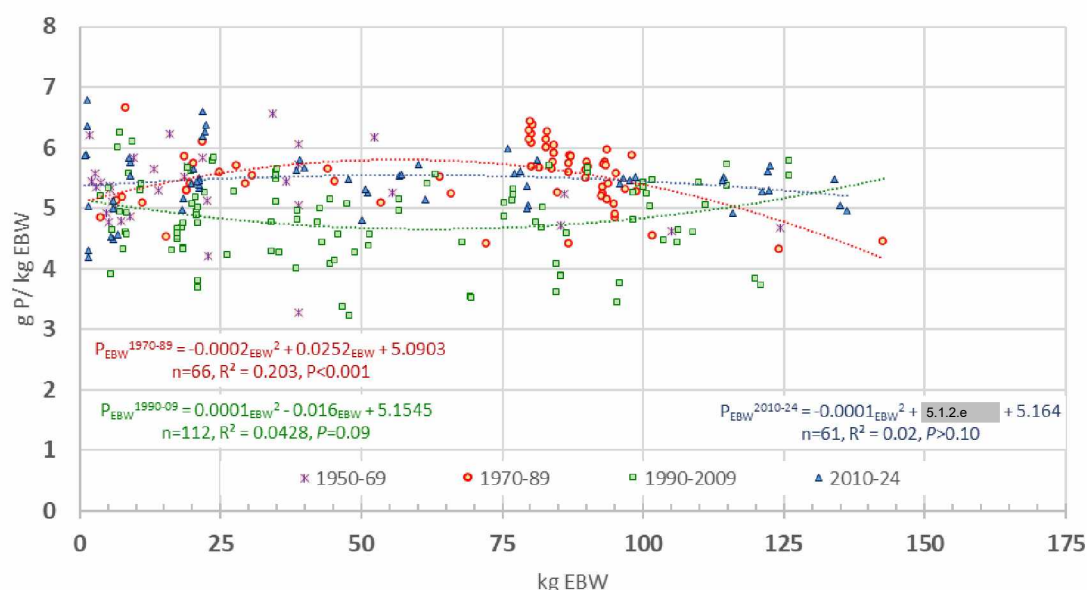


Figure 4 Phosphorous content in the empty body (P_EBW) in relation to EBW, with tested quadratic regression equations within each study period.

Observations with dietary phosphorus content showed that P_diet and DigP decreased with time (Table 10) and that diets from the 2010-2024 period had lower P contents than for the period 1990-2009. For the 2010-2024 period, microbial phytase was supplemented to all feeds in the studies reported by Andretta et al. (2014) and Ruiz-Ascacibar et al. (2019) whereas no phytase supplementation was applied in the studies reported by Peters et al. (2010), Boddicker et al. (2011), 5.1.2.e et al. (2013, 2018), Andretta et al. (2016) and Remus et al. (2019). In the studies of Columbus (2008, 2010), Lautrou et al. (2021) one of the dietary treatments received a phytase supplementation. Hence, the use of phytase likely contributed to the body P content despite a relatively low total dietary P content.

Table 10 Mean dietary total (P_diet) and digestible (DigP) phosphorus content calculated for studies of all weight categories, based on slaughter studies.

Period	1950-1969	1970-1989	1990-2009	2010-2024	RMSE	Stat	R ²
n	12	50	89	50			
P_diet, g/kg	6.35 ^a	7.19 ^b	6.35 ^a	5.18 ^c	0.80	P***, SP***	0.78
n	12	50	89	34			
DigP, g/kg	3.51 ^a	4.03 ^b	3.37 ^a	2.54 ^c	0.57	P***, SP***	0.82

Values in the table are presented as means and root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex. P-value: ns: > 0.05, * < 0.05, ** < 0.01, *** < 0.001.

3.2.3.2 Analysis of the category growing finishing pigs (Va 4)

For the category Va 4 (40-142 kg), 154 observations with body P contents were available from slaughter studies. The mean body weight and phosphorus content are presented in 5.1.2.e. Although the body weight of pigs was numerically higher for observations of periods 1970-1989 and 2010-2024 than for the 1950-1969 period, the differences were not statically different.

A numerically smaller within-period variation of body P contents was observed for the period 2010-2024 than for other periods (Figure 5). The mean values for P_EBW and P_LW of the 2010-2024 period were not different from the period 1970-1989, but higher than in the periods 1950-1969 and 1990-2009. The P contents of the diets supplied to growing finishing pigs were lower in the 2010-2024 period than in previous periods (Table 12).

Table 11 Body weights and phosphorus contents for empty (P_EBW) and live body weight (P_LW) calculated per period for growing-finishing pigs (Va 4 category) with the slaughter method.

Period	1950-1969	1970-1989	1990-2009	2010-2024	RMSE	Stat	R ²
n	11	49	62	32			
EBW, kg	63.8	85.4	79.7	85.3	23.6	ns	0.27
LBW, kg	67.4	91.3	84.0	88.5	24.4	ns	0.28
Gut fill, kg	3.7 ^{ac}	5.8 ^b	4.3 ^c	3.2 ^a	1.3	P***, SP***, Sx*	0.62
P_EBW, g/kg	5.11 ^a	5.57 ^b	4.74 ^c	5.42 ^b	0.35	P***, SP***	0.80
P_LW, g/kg	4.82 ^a	5.21 ^b	4.48 ^c	5.24 ^b	0.33	P***, SP***	0.80

Values in the table are presented as means and root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex. LBW is added as covariable for P_EBW and P_LW. P-value: ns: > 0.05, * < 0.05, ** < 0.01, *** < 0.001.

Table 12 Dietary total (P_diet) and digestible (DigP) concentrations in phosphorus calculated for Va 4 category with slaughtering measurements.

Period	1950-1969	1970-1989	1990-2009	2010-2024	RMSE	Stat	R ²
n	10	44	59	32			
P_diet, g/kg	6.38 ^{ab}	7.05 ^b	6.27 ^a	4.89 ^c	0.89	P***, SP***	0.76
n	10	44	59	30			
DigP, g/kg	3.69 ^a	3.87 ^a	3.16 ^b	2.47 ^c	0.61	P***, SP***	0.77

Values in the table are presented as means and root mean square error. P value from analysis of variance including the fixed effects of study-within-period, period and sex.

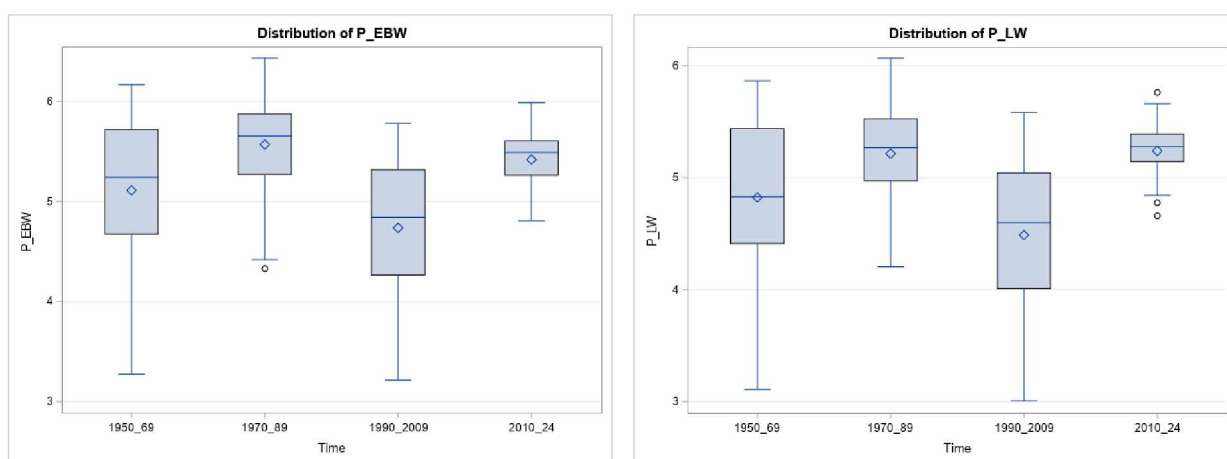


Figure 5 Distribution of mean P content in empty body weight (P_EBW) and live weight (P_LW) per period for growing finishing pigs (Va 4 weight category) using the slaughter method (154 observations). For explanation of box-plots, see Figure 3.

3.2.3.3 Analysis of the category nursery pigs (Va 3)

For the Va 3 weight category (19.5-31.5 kg), 43 observations with body P contents were available from slaughtered animals (Table 13). Empty body weight and live weight of pigs were slightly lower for observations of period 2010-2024 than for the previous periods. Similarly to the growing finishing pigs (Va 4 category), mean values for P_EBW and P_LW of the 2010-2024 period were not different from the 1970-1989 period, but higher than in the 1950-1969 and 1990-2009 periods (Table 13, Figure 6). The amount of data for dietary P contents for nursery pigs were not sufficient for statistical analysis of diets for pigs of this category.

Table 13 Body weight and phosphorus contents in empty (P_EBW) and live body weight (P_LW) calculated per period for nursery pigs (Va 3 category) with the slaughter method.

Period	1950-1969	1970-1989	1990-2009	2010-2024	RMSE	Stat	R ²
n	4	8	18	13			
EBW, kg	21.7 ^a	21.3 ^{ab}	21.4 ^{ab}	20.8 ^b	0.36	P***, SP***	0.99
LBW, kg	23.1 ^a	23.2 ^a	23.1 ^a	22.2 ^b	0.37	P***, SP***	0.99
Gut fill, kg	1.5 ^a	1.9 ^b	1.7 ^{ab}	1.4 ^a	0.33	P*, SP**	0.90
P_EBW, g/kg	5.21 ^a	5.63 ^b	4.93 ^c	5.67 ^b	0.20	P***, SP***, EBW**	0.97
P_LW, g/kg	4.89 ^a	5.17 ^b	4.56 ^c	5.37 ^b	0.22	P***, SP***, LBW**	0.96

Values in the table are presented as means and root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex (no effect). LBW was added as covariable for P_EBW and P_LW. P-value: ns: > 0.05, * <0.05, ** < 0.01, *** < 0.001.

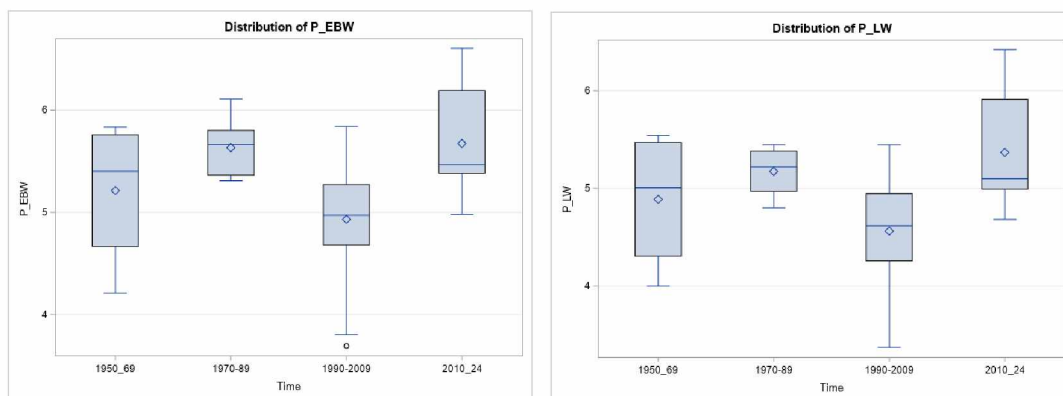


Figure 6 Distribution of P in empty body weight (P_EBW) and live weight (P_LW) per period for nursery pigs (Va 3 weight category) using the slaughter method (43 observations). For explanation of box-plots, see Figure 3.

3.2.3.4 Analysis of the category weaned pigs (Va 2)

For the Va 2 weight category (5.0-11.9 kg), 35 observations with body P contents were available from slaughtered animals (Table 14, Figure 7). Empty body weight and live body weight of pigs was not influenced by the period of the study. Mean values for P_EBW and P_LW of the 1970-1989 period were higher than for other periods.

Table 14 Body weights and phosphorus contents for empty (P_{EBW}) and live body weight (P_{LW}) calculated per period for nursery pigs (Va 2 category) with the slaughter method.

Period	1950-1969	1970-1989	1990-2009	2010-2024	RMSE	Stat	R ²
n	9	4	14	8			
EBW, kg	6.6	8.3	7.9	7.1	1.3	SP*	0.77
LBW, kg	6.9	8.7	8.4	7.6	1.4	SP*	0.78
Gut fill, kg	0.3	0.4	0.5	0.5	0.1	SP***	0.92
P_{EBW} , g/kg	5.10 ^a	5.53 ^b	5.13 ^a	5.11 ^a	0.21	P*, SP***	0.95
P_{LW} , g/kg	4.87 ^a	5.27 ^b	4.85 ^a	4.83 ^a	0.20	P**, SP***	0.95

Values in the table are presented as means and root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex. LBW was added as covariable for P_{EBW} and P_{LW} . P -value: ns: > 0.05, * < 0.05, ** < 0.01, *** < 0.001.

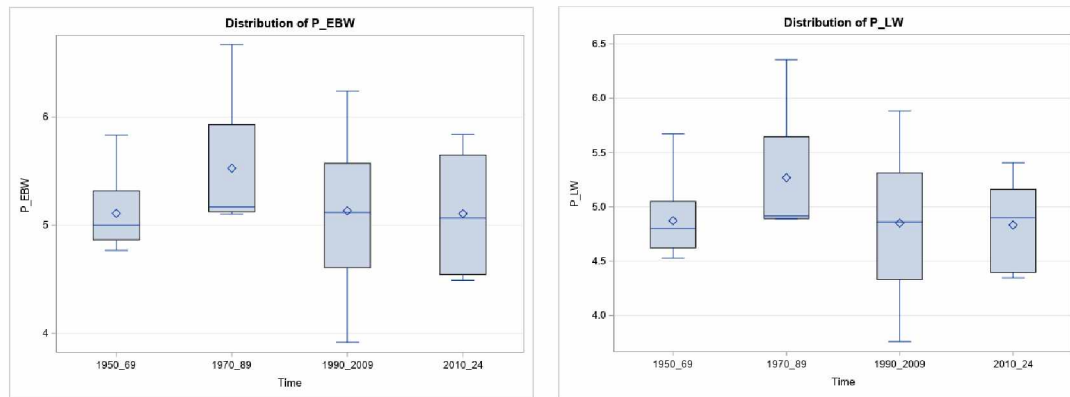


Figure 7 Distribution of P in empty body weight (P_{EBW}) and live weight (P_{LW}) per period for weaned pigs (Va 2 weight category) using the slaughter method (35 observations). For explanation of box-plots, see Figure 3.

3.3 Body nitrogen content

3.3.1 Analysis for the total dataset

From the total dataset with 627 observations, 536 observations included N_{EBW} and 560 included N_{LW} . Around 53% were observations of growing finishing pigs (Va 4 category), whereas 12 and 16% were weaned piglets (Va 2) and nursery pigs (Va 3), respectively (Table 15). Mean body weight differed among the four periods in the dataset with all observations. For the 1950-1969 period, EBW and LBW were lower than for other periods (Table 16; Figure 8). For the 2010-2024 period, data were compared between the DXA and slaughter method. N_{LW} and N_{EBW} values were not different ($P > 0.05$) between the two methods. Consequently, the analysis was conducted for observations of both methods in this period. These observations were grouped per period and displayed in 5.1.2.e. The regression analysis showed that, within each period, N_{EBW} was quadratically related to EBW, with a maximum value in the weight range 70-100 kg, for the periods 1970-1989 and 2010-2024.

Table 15 Dispersion of observations with available N_{EBW} and N_{LW} values among weight category.

Code	Va1	Va2	Va3	Va4	Other weights	Total
Range, kg LBW	< 2	5 -11.9	19.5-31.5	40-142		
N_{EBW} , n	6	65	84	285	96	536
N_{LW} , n	6	65	90	303	96	560

Parameters and P value of the equations from regression analysis using the Proc reg of SAS.

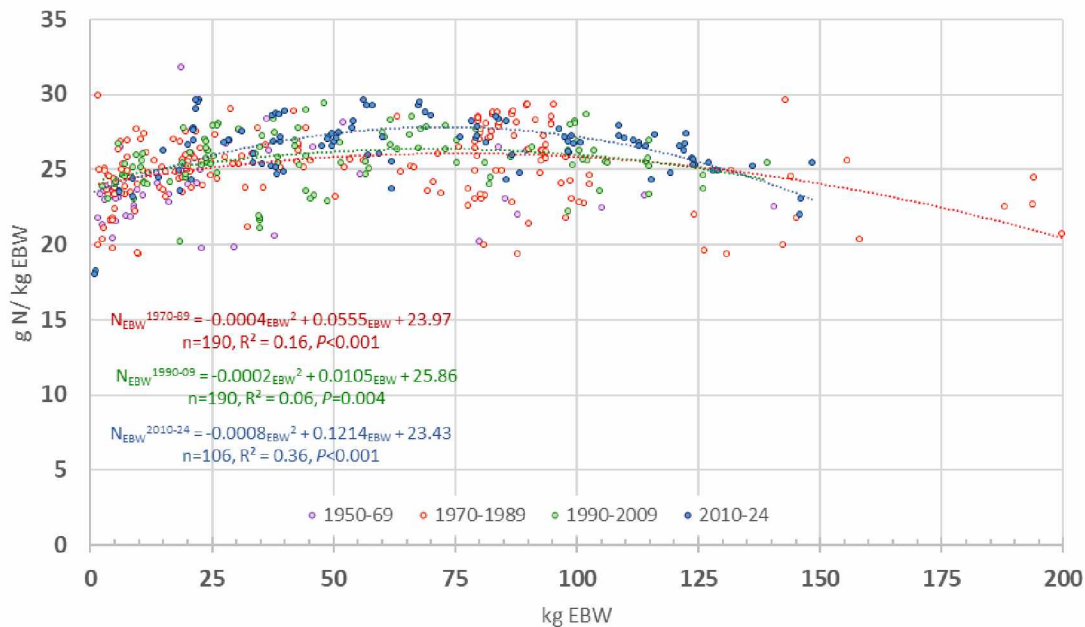


Figure 8 Nitrogen content in the empty body (N_{EBW}) in relation to EBW, with quadratic regression equations by study period.

Mean body N content gradually increased during the four periods of this study, both in EBW and LBW (Table 16, Figure 9). The increase in the period 2010–2024 compared to the period 1990–2009 was 0.86 and 0.84 g/kg for N_{EBW} and N_{LW} , respectively.

Table 16 Body weights and body N content calculated for empty (EBW) and live body weight (LW) by period for the total database.

		1950-1969	1970-1989	1990-2009	2010-2024	RMSE	P value	R ²
N_{EBW}	Observations, n	50	190	190	106			
	EBW, kg	29.3 ^a	56.1 ^{bc}	53.5 ^b	66.8 ^b	32.1	P*, SP***,	0.54
	Gut fill, kg	2.0 ^a	4.0 ^b	3.2 ^c	3.5 ^c	2.0	P*, SP***	0.61
	N-EBW, g/kg	23.76 ^a	25.21 ^b	25.60 ^b	26.46 ^c	1.46	P***, SP***, Sx***, EBW***	0.72
N_{LW}	Observations, n	50	190	190	130			
	LBW, kg	31.3 ^a	60.1 ^{bc}	56.7 ^b	71.7 ^c	34.4	P*, SP***	0.53
	N_LW, g/kg	22.38 ^a	23.47 ^b	24.11 ^c	25.05 ^d	1.37	P***, SP***, Sx***, LBW***	0.73

Values in the table are presented as means. RMSE: root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex (Sx). EBW or LBW is added as covariable for N_{EBW} and N_{LW} . P-value: ns: > 0.05, * < 0.05, ** < 0.01, *** < 0.001.

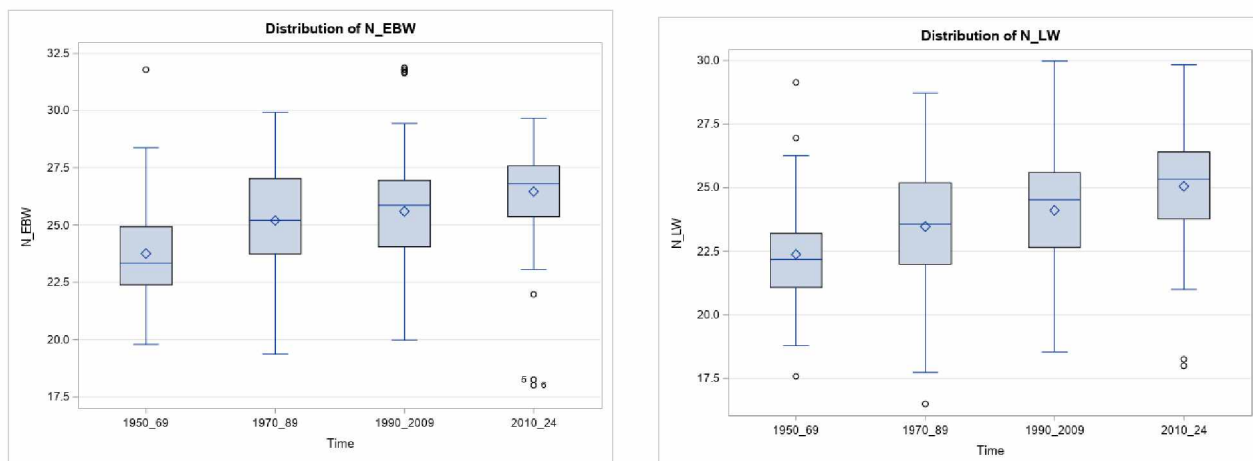


Figure 9 Distribution of body nitrogen (N) content calculated for empty (EBW) and live body weight (LW) by period for the total dataset (539 and 563 observations, respectively). For explanation of box-plots, see Figure 3.

3.3.2 Analysis for growing finishing pigs (category Va 4)

For the Va 4 weight category (40-142 kg), a total of 285 and 303 observations were collected for N_EBW and N_LW, respectively. The results of the analysis are shown in 5.1.2.e and Figure 10. The data indicated an increase of the body N content with year of study publication, with substantial variation within each period. Nitrogen content in LBW or EBW was higher for the 2010-2024 period than for previous periods (Figure 10).

Table 17 Body weight and body N content calculated for empty (EBW) and live body weight (LW) by period for growing finishing pigs (Va 4 weight category).

		1950-1969	1970-1989	1990-2009	2010-2024	RMSE	P value	R ²
N_EBW	Observations, n	11	95	104	75			
	EBW, kg	76.0	81.6	79.2	81.1	25.9	n.s.	0.22
	Gut fill, kg	5.7 ^a	6.2 ^a	4.6 ^b	4.2 ^b	1.6	P***, SP***	0.65
	N_EBW, g/kg	24.48 ^a	25.91 ^b	25.43 ^b	26.87 ^c	1.11	P***, SP***, Sx***, EBW***	0.81
N_LW	Observations, n	11	95	104	93			
	LBW, kg	81.8	87.9	83.8	87.3	28.2	n.s.	0.19
	N_LW, g/kg	22.65 ^a	24.06 ^b	23.98 ^b	25.39 ^c	1.06	P***, SP***, Sx***, EBW***	0.83

Values in the table are presented as means. RMSE: root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex (Sx). EBW or LBW was added as covariable for N_EBW and N_LW. P-value: n.s.: > 0.05, * < 0.05, ** < 0.01, *** < 0.001. For observations from the DXA study of Remus et al. (2019), the N and protein contents were only determined in LBW.

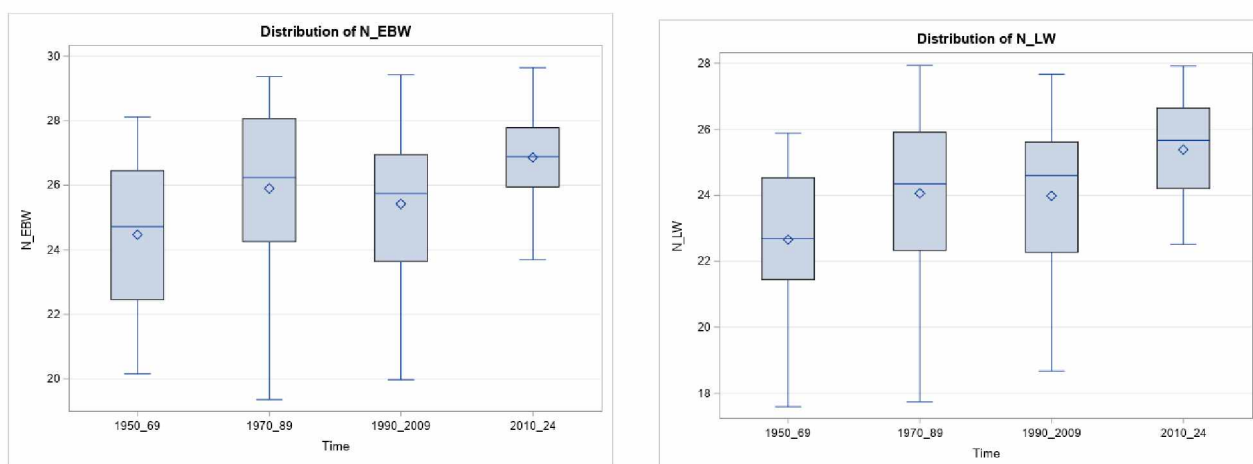


Figure 10 Distribution of body nitrogen (N) content calculated for empty (EBW) and live body weight (LW) of growing finishing pigs (category Va 4) per period (285 and 303 observations, respectively). For explanation of box-plots, see Figure 3.

3.3.3 Analysis for nursery pigs (category Va 3)

Table 18 Body weight and body N content calculated for empty (EBW) and live body weight (LW) by period for nursery pigs (Va 3 weight category).

		1950-1969	1970-1989	1990-2009	2010-2024	RMSE	P value	R ²
N_EBW	Observations, n	8	24	36	16			
	EBW, kg	22.9 ^a	21.5 ^b	22.9 ^a	22.1 ^{ab}	1.08	P**, SP***	0.96
	Gut fill, kg	1.8 ^{ab}	2.0 ^b	1.6 ^{ac}	1.5 ^c	0.3	P***, SP***	0.95
	N_EBW, g/kg	24.55 ^a	25.47 ^b	26.02 ^c	27.10 ^d	0.49	P***, SP***	0.98
N_LW	Observations, n	8	24	36	22			
	LBW, kg	24.7 ^a	23.4 ^b	24.4 ^{ab}	24.2 ^{ab}	1.1	P**, SP***	0.96
	N_LW, g/kg	22.71 ^a	23.37 ^b	24.36 ^c	25.25 ^d	0.53	P***, SP***	0.98

Values in the table are presented as means. RMSE: root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex (Sx). EBW or LBW was added as covariable for N_EBW and N_LW. P-value: n.s.: > 0.05, * < 0.05, ** < 0.01, *** < 0.001. For observations from the DXA study of Remus et al. (2019), the N and protein contents were only determined in LBW.

For the Va 3 weight category (19.5-31.5 kg), a total of 82 and 88 observations were collected for N_EBW and N_LW, respectively. The results of the analysis are shown in 5.1.2.e and Figure 11. The data indicated an increase of the body N content with the year of the study publication. Nitrogen content in LBW or EBW was higher for the 2010-2024 period than for previous periods (Figure 11).

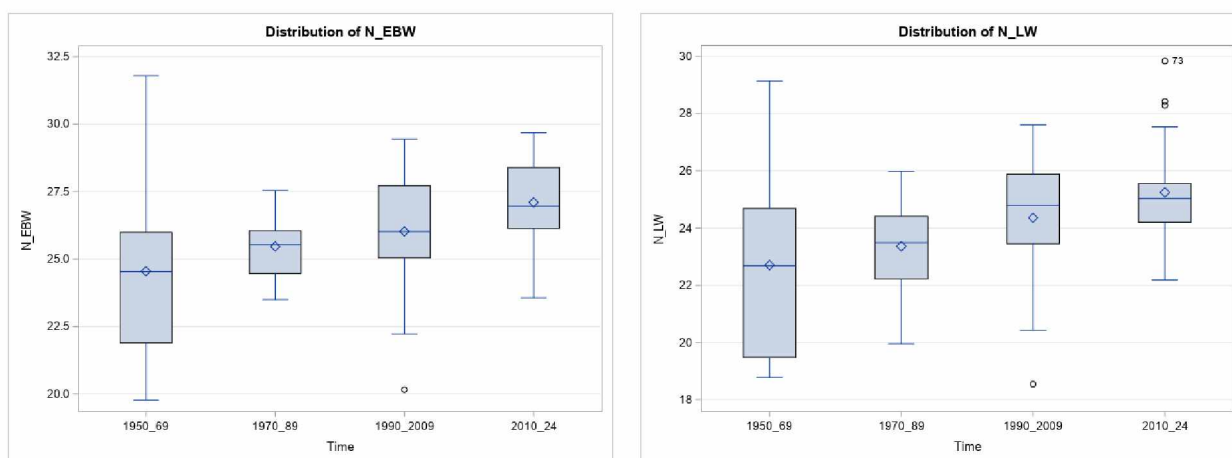


Figure 11 Distribution of body nitrogen (N) content calculated for empty (EBW) and live body weight (LW) of nursery pigs (category Va 3) per period (82 and 88 observations, respectively). For explanation of box-plots, see Figure 3.

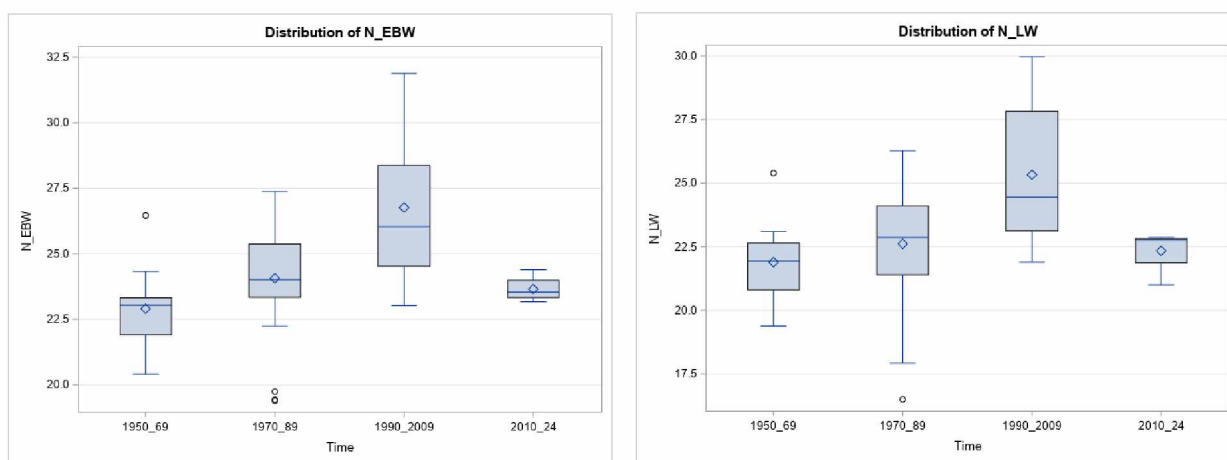
3.3.4 Analysis for weaned piglets (category Va 2)

For the Va 2 weight category (5-11.9 kg), a total of 65 observations were collected for N_EBW and N_LW. The results of the analysis are shown in 5.1.2.e and Figure 12. The data indicated a higher nitrogen content in LBW or EBW for the 1990-2009 period than for other periods. However the number of observations (n=4) for the 2010-2024 period was very low.

Table 19 Body weight and body N content calculated for empty (EBW) and live body weight (LW) by period for weaned piglets (category Va 2).

		1950-1969	1970-1989	1990-2009	2010-2024	RMSE	P value	R ²
N_EBW	Observations, n	13	26	22	4			
	EBW, kg	7.1	7.4	7.4	7.4	1.8	n.s.	0.70
	Gut fill, kg	0.3	0.5	0.4	0.5	0.2	SP***	0.90
	N_EBW, g/kg	22.90 ^a	24.06 ^a	26.76 ^b	23.66 ^a	1.47	P**, SP*	0.91
N_LW	Observations, n	13	26	22	4			
	LBW, kg	7.4	7.9	7.8	7.9	1.9	n.s.	0.71
	N_LW, g/kg	21.89 ^a	22.61 ^a	25.33 ^b	22.34 ^a	1.52	P*, SP*	0.90

Values in the table are presented as means. RMSE: root mean square error. P value from analysis of variance including the fixed effects of period (P), study-within-period (SP) and sex (Sx). EBW or LBW was added as covariable for N_EBW and N_LW. P-value: n.s.: > 0.05, * <0.05, ** < 0.01, *** < 0.001.



See Figure 3.

Figure 12 Distribution of body nitrogen (N) content calculated for empty (EBW) and live body weight (LW) of nursery pigs (category Va 2) per period (65 observations).

4 Discussion

The study described in this report was conducted to determine whether the N and P content in the body of growing pigs, as adopted in the WUM-model to calculate N and P excretion was in agreement with recent literature and give recommendations for an update when appropriate. This literature based approach was previously applied by Jongbloed and Kemme (2002), Jongbloed et al., (2002a), Tamminga et al., (2009) and Jongbloed (2010). Similar to these previous reviews, data were collected from studies published in scientific literature, generally originating from Europe and 5.1.2.e Pigs and experimental conditions used in these studies were considered representative for Dutch pig production since pig breeds used were largely similar and diets were not limiting in protein, amino acids and minerals to assure that pigs could exploit their growth potential. This approach allowed to create a robust dataset of body composition of pigs.

The majority of studies in this review used the slaughter method to determine body composition, but in the last period five studies used the DXA method to determine body composition of live animals. For N the results of the two methods were in good agreement, but the P content was consistently lower in studies with DXA. The reason might be related to the assumptions used to estimate P content from bone mineral content determined with DXA. The studies calculated total body P assuming that 18% of bone mineral content was phosphorus and that DXA bone mineral content represented 80% of total body phosphorus (Andretta et al., 2014, 2016; Lautrou et al., 2021). Because of uncertainties in this approach and consistent differences with the slaughter method, these five studies were not taken into account for body P content.

Only a limited number of studies measured both LBW and EBW (including blood and viscera) by weighing the different carcass components, blood and organs. For the present study, the missing values for EBW were calculated from an equation to relate EBW to LBW. Accordingly, the weight of gut fill was generally calculated, not measured. Furthermore, the P and N content of the digestive contents was generally estimated as a proportion of diet intake because of the lack of chemical analysis of this content in most studies. Consequently, N and P as analysed and expressed in g per kg of EBW by most authors provide a reliable estimate, whereas there is some uncertainty in the values expressed in LBW due to the contribution of gut fill.

The studies were grouped in four periods: 1950-1969, 1970-1989, 1990-2009 and 2010-2024 in order to analyse the evolution of N and P contents in the body and other characteristics over time. Correlations between characteristics in the complete dataset were analysed. The period or year of publication of studies in the data set was positively correlated to daily gain, LBW and EBW, and N in LBW and EBW. This increase over time in performance and body protein content may be caused by improvement in performance through genetic selection, feeding and management practices. The year of publication was negatively correlated to total and digestible P content in the diet and to P content in EBW and LBW. This may result from lower P content in pig diets enabled by better knowledge of P digestibility and absorption and the aim to increase the efficiency of P retention and reduce the excretion of P in manure. In the last period, use of microbial phytase also contributed to a lower total P content in the diet.

Mean body N content in growing pigs appears to have gradually increased over time. Mean body P content varied substantially between periods, with an overall slightly decreasing trend. In Table 20, the mean results of N and P in live weight for studies in the last period (2010-2024) have been included in comparison to the present values of the Dutch manure policy. In addition, allometric relationships between body weight and body N and P content were determined (Appendix 3), in line with Jongbloed et al. (2002a). This approach allows to combine information of pigs of all weight classes and subsequently estimate body N and P content at a specific body weight. Using this approach, N and P content was calculated for pigs with live body weight of Va 2 (10 kg), Va 3 (25 kg), and fattening pigs of 85 kg and 125 kg (i.e. Va 4), and included in 5.1.2.e The calculated N content of fattening pigs at 125 kg is lower than at 85 kg, 24.7 vs 25.2 g/kg, which is explained by the increase in body fat mass and decrease in lean tissue when pigs grow older and heavier.

Table 20 Nitrogen and phosphorous content (g/kg live body weight) in the body of growing pigs in different weight categories as adopted by Mestbeleid 2024 and derived in this study for the last period of data collection (2010-2024), with number of observations in parentheses.

Pig weight category	Code	LBW ¹⁾	Mestbeleid		Present study (2010-2024)				Proposed new values	
					Data set		Allometry			
			N	P	N	P	N	P	N	P
Newborn piglets ²⁾	Va 1	1.4-1.6	18.7	6.15	-	-	-	-	18.7	6.15
Weaned piglets, approx. 4 weeks of age	Va 2	8-10	24.4	5.32	22.3 (4)	4.83 (8)	24.0	5.17	24.0	5.17
Pig of around 10 weeks of age (ca. 25 kg)	Va 3	23-25	24.8	5.32	25.3 (22)	5.37 (13)	25.4	5.20	25.3	5.25
Fattening pigs	Va 4	86-88 125	25.0	5.37	25.4 (93)	5.24 (32)	25.2 5.23 24.7 5.25		25.0	5.25

1) Mean live body weight obtained from the data set or used for calculations with allometric equations.

2) For Va 1 weight category, no new observations for the period 2010-2024 were obtained. Hence, not changes in reference values are proposed

Based on the results in 5.1.2.e we propose to slightly revise the reference values for body composition of pigs in category Va 2, Va 3 and Va 4. For pigs in Va 1, no changes are proposed since the dataset did not contain new observations for the period 2010-2024.

For pigs of category Va 2, both the allometric relationships and the data of 2010-2024 suggest a small decrease in N and P content. The mean N content of the latter dataset of 22.3 g/kg for the data of 2010-2024 is out of the range of other values and likely influenced by the small number of observations. Hence, reference values for N and P content of 24.0 and 5.17 g/kg are proposed.

For pigs of category Va 3, N content in the recent data set and derived from the allometric approach are similar, the mean value reflects a small increase in N content. The mean P content in the recent data was somewhat higher than the value derived from the allometric approach and did not reflect the overall decrease in body P content as discussed before. Results of the two methods were combined and reference values for N and P content of 25.3 and 5.25 g/kg are proposed. The P content of 5.25 g/kg for category Va 3 and Va 4 (see below) reflects the largely constant P content over a wide body weight range in 2020-2024 as illustrated in 5.1.2.e and the allometric relationship in 5.1.2.e in 5.1.2.e

For pigs of category Va 4, both the recent dataset and the allometric relationship suggest an increase in N-content and decrease in P-content as discussed above. However, this category is mainly used for slaughter pigs with a body weight (well) above 100 kg. This needs to be taken into account in the reference values and negates the increase in mean N content. Therefore, reference values for N and P content of 25.0 and 5.25 g/kg are proposed, based on the mean of the dataset of 2010-2024 and the allometric value for pigs with a body weight of 125 kg.

5 Conclusions

An extensive literature search and data analysis was conducted to update reference values for N and P content in the body of growing pigs. The analysis included studies considered representative for Dutch pig production, using slaughter and carcass analysis for N and P content and additionally dual-energy X-ray absorptiometry (DXA) for N content only since body P content using DXA was consistently lower than in studies using the slaughter method. Data were analysed in four periods from 1960 to 2024. Body N content appeared to have increased over time, whereas P content varied substantially between period, with an overall decreasing trend. Based on mean results and allometric relationships, slight changes in the reference values of body N and P content are proposed. The proposed standards are 24.0 g N and 5.17 g P per kg LBW for piglets of category Va 2, 25.3 g N and 5.25 g P per kg LBW for pigs of category Va 3 and 25.0 g N and 5.25 g P per kg LBW for pigs of category Va 4.

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Appendix 1 Studies in the period 2010-2024

Authors	Research aim	Observation selection	Method	N	P	Live weight, kg	Weight normalization	P content**	N content**
Andretta et al., 2014	Precision feeding	3-phase, multiphase	DXA measurements	Protein (kg)	BMC	40-136	EBW calculated from LBW using equation A, *	gut fill P content estimated from undigestible dietary P	gut fill N content estimated from 40% non-digested total N
Andretta et al., 2016	Precision feeding	3-phase, 100-110 % lys	DXA measurements	Protein (kg)	BMC	30-119	EBW calculated from LBW using equation A	gut fill P content estimated from undigestible dietary P	gut fill N content estimated from 40% non-digested total N
Arthur et al., 2011	Growth and allometric functions	all	DXA + slaughtering	Total protein, kg		36-155	EBW calculated from LBW using equation A		gut fill N content estimated from 40% non-digested total N
Bee et al., 2023	protein-restricted diet	High protein diet	DXA measurements	Total protein, g		104	EBW calculated from LBW using equation A		gut fill N content estimated from 40% non-digested total N
5.1.2.e et al., 2013	Dietary P level	110-130% P requirement	Serial slaughtering + sampling + grinding + chem. analysis	g/ kg EBW	g/ kg EBW	50-125 kg	Gut fill weighed	gut fill P content estimated from undigestible dietary P	gut fill N content estimated from 40% non-digested total N (for a part of observations)
5.1.2.e et al., 2018	P metabolism	all	Slaughtering + sampling +grinding + chem. analysis	g/ kg EBW	g/ kg EBW	1-22	Gut fill weighed	gut fill P content estimated from undigestible dietary P	
Boddicker et al., 2011a,b	Feed restriction and genetics	all	Slaughtering + chem. analysis	Protein, g/kg carcass		58-115	Blood volume estimated, [C]		blood N content estimated [D]; gut fill N content estimated from 40% non-digested total N
Columbus et al., 2008	Dietary P level	all	Slaughtering + sampling +grinding + chem. analysis	% EBW	% EBW	23	Blood volume estimated, [C]	gut fill P content estimated from 50% non-digested total P	blood N content estimated [D]; gut fill N content estimated from 40% non-digested total N
Columbus et al., 2010	Dietary P level	all	Slaughtering + sampling + grinding + chem. analysis	% EBW	% EBW	22-23	Blood volume estimated, [C]	gut fill P content *** estimated from 50% non-digested total P	blood N content estimated [D]; gut fill N content estimated from 40% non-digested total N
Hulshof et al., 2016	Feed ingredient processing	Raw and processed ingredients with AA	Slaughtering + sampling +grinding + chem. analysis	g/ kg EBW	g/ kg EBW	41-42	Gut fill weighed		gut fill N content estimated from 40% non-digested total N
5.1.2.e et al., 2021	predicting chemical body composition	all	Serial slaughtering + sampling + grinding + chem. analysis	Total protein, g	Total P, g	20-104	LBW calculated from EBW using equation B	gut fill P content *** estimated from 50% non-digested total P	gut fill N content estimated from 40% non-digested total N
Lautrou et al., 2021	Dietary P & Ca utilization	100% or 60-100% DigP	DXA measurements		g P body	30-132	EBW calculated from LBW using equation A	gut fill P content estimated from undigestible dietary P	
Peters et al., 2010	organic and inorganic micromineral source	all	Slaughtering +grinding + chem. analysis		g/ kg EBW	1.4-6.7		gut fill P content estimated from sow milk composition [F]	
Remus et al., 2019	Ideal protein profile	100-130% threonine requirement	DXA measurements	kg protein		25-135	carcass weight, gut fill weight not published		N and protein contents only established for LBW.

Ruiz-Ascacibar et al., 2019	Mineral composition, CP restriction	Control group	Serial slaughtering + sampling + grinding + chem. analysis	g protein	g/kg EBW	1.5-136	gut fill P content estimated from undigestible dietary P	gut fill N content estimated from 40% non-digested total N
Totafurno et al., 2019, 2020	Lysine supply	110% lysine requirement	Serial slaughtering + 1/2 carcass grinding + chem. analysis	g/kg EBW	14-124	viscera and gut fill weighed separately		gut fill N content estimated from 40% non-digested total N; blood and viscera N content estimated [D, E]

A. $EBW, kg = 0.0002 \times LBW^2 + 0.9226 \times LBW + 0.1484$, kg. (from 5.1.2.e and Blok, 2017)

B. Reverse equation of 5.1.2.e and Blok (2017)

C. Blood volume: 6.0%, 4.0% and 3.2% of carcass weight in nursery, growing and finishing pigs, respectively (Vaissaire, 1982)

D. Protein composition of blood : 16% (adapted from Walker, 1977).

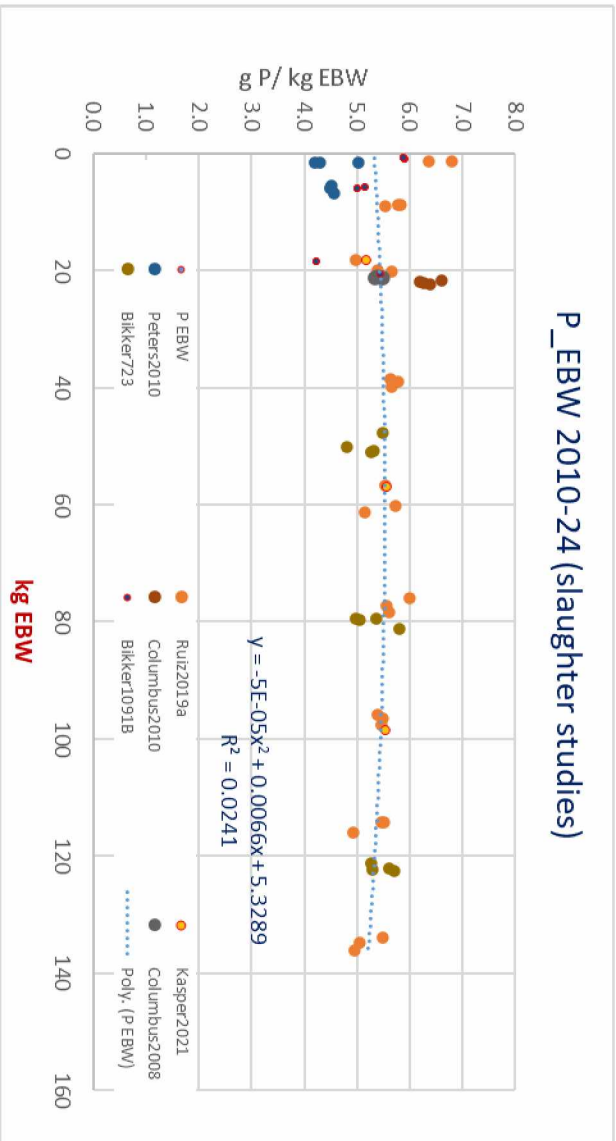
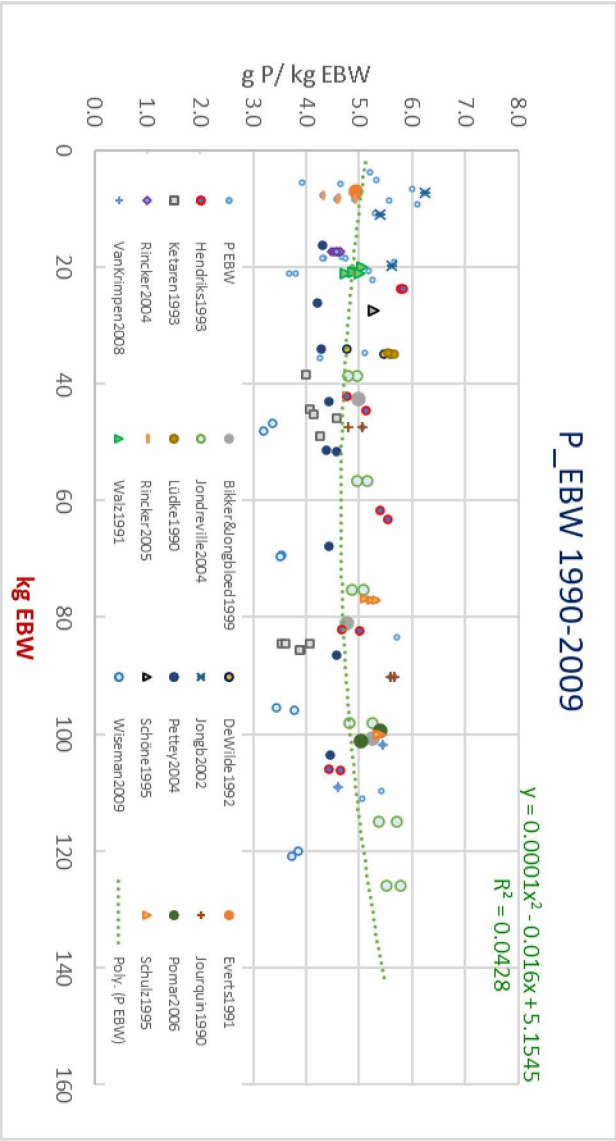
E. Protein composition of viscera : 13.9% in growing pigs; 14.7% in finishing pigs (Totafurno, 2018)

F. Adapted from Perrin et al. (1955) : 7.1 g P / kg milk

*Andretta et al. (2014) indicated that they applied a 0.21% reduction to LBW per hour of fasting to eliminate the influence of the fasting duration (16 hours). This final LBW was kept in the study data set.

**For gut fill P and N content, values were based on 25 % solid content of the gut fill

Appendix 2 Empty body phosphorus in the period 1990-2009 and 2010-2024



Appendix 3 Allometric body composition

Allometric equations were used to relate total body N and P mass to empty and live body weight. After logarithmic transformation linear (1) and a quadratic equations (2) were determined.

$$1) \quad \ln(Y) = a + b \times \ln(X)$$

$$2) \quad \ln(Y) = a + b \times \ln(X) + c\ln(X)^2$$

With $Y = P_body, N_body$ in g per kg EBW or LBW and $X = EBW \text{ or } LBW$ in kg.

For each period (1950-1969, 1970-1989, 1990-2009 and 2010-2024), the observations in the data set were transformed to natural logarithms. Parameters a, b and c of the linear and quadratic model were estimated for each period and for the periods 1990-2009 and 2010-2024 combined, using the Proc Model from SAS. Results for phosphorous and nitrogen are displayed in Tables A1-A2 and A3-A4 and in 5.1.2.e and A2, respectively.

For phosphorus, the allometry calculations showed significant linear equations. However, the conditions for homoscedasticity and normality were not always met in the present study. In the quadratic model, the quadratic component was not significantly different from zero. Similarly, Jongbloed et al. (2002a) also reported that the quadratic terms in their equations were not significant.

The graphical analysis shows that the equations were influenced by the period of the data set. The parameters a and b of the linear equations for the periods 1970-1989 and 2010-2024 were similar, so that the curves were very close and showed an increasing P content as the weight increased, while for the other periods the body P contents tended to decrease as the pigs were heavier.

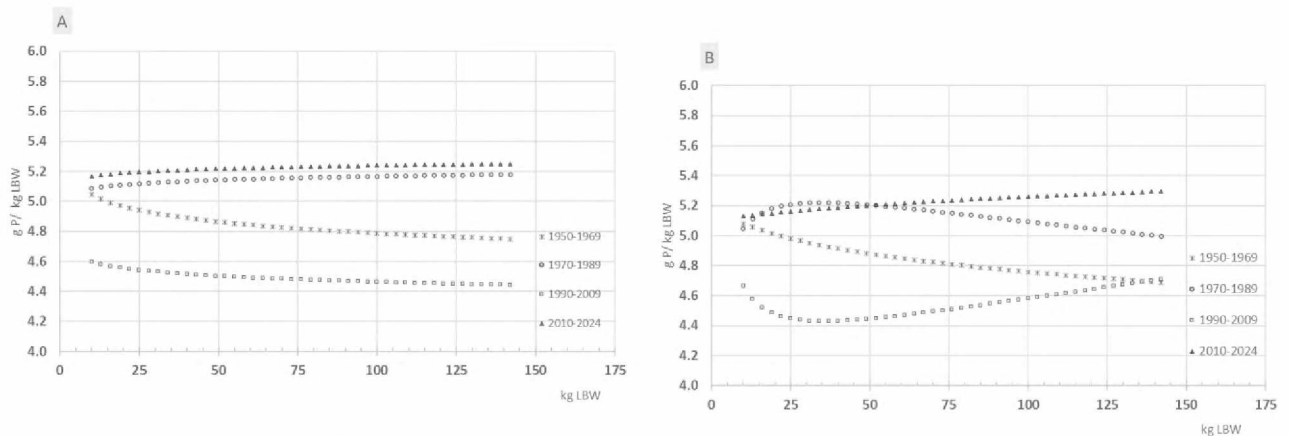
For nitrogen, the allometry calculations were satisfactory. The conditions of statistical validity were met and the intercepts in the three-parameter equations were significant for the 2010-2024 and grouped 1990-2024 periods.

Graphical analysis shows that body N content increased with individual weight when a linear equation is applied. Conversely, using a quadratic equation the body content increased and reached a maximum around 50 kg and then gradually decreased.

Table A20 Results for the linear and quadratic equations fitted for body weights (kg) and body phosphorus content relative to live body weight (g/kg LBW) by period for all weight classes.

	Obs.		Parameters			Statistics			
	n	a	b	c	RMSE	R ²	Variance	Normality	Log likelihood
lnP = a + b*lnLBW									
1950-1969	34	1.671***	0.977***		0.13	0.99	0.22	<0.001	22.0
1970-1989	66	1.611***	1.067***		0.09	0.99	0.61	0.91	62.8
1990-2009	112	1.554***	0.987***		0.14	0.97	0.17	0.56	59.1
2010-2024	60	1.628***	1.006***		0.09	0.99	<0.001	0.11	57.6
1990-2024	172	1.597***	0.989***		0.14	0.98	0.83	0.49	89.3
lnP = a + b*lnLBW + c*(lnLBW)²									
1950-1969	34	1.638***	1.006***	-0.005	0.13	0.99	0.27	<0.001	22.1
1970-1989	66	1.376***	1.156***	-0.022	0.09	0.99	0.77	0.99	63.6
1990-2009	112	1.898***	0.771***	0.032 ^t	0.14	0.98	0.19	0.57	61.0
2010-2024	60	1.643***	0.990***	0.003	0.09	0.99	<0.001	0.11	52.7
1990-2024	172	1.691***	0.910***	0.013*	0.14	0.98	0.70	0.32	91.3

For each parameter, a t-test was used to evaluate if the estimate was significantly different from zero: t p<0.10; * p<0.05; ** p<0.01; *** p<0.001. Variance was assessed by the Breusch–Pagan test and normality by the Kurtosis test; a low probability for either test points to a violation of the null hypothesis. Measurements obtained using DXA method were excluded of the data set.



5.1.2.e

Body content of P per kg of live body weight (LBW) and by period estimated trough linear (A) and quadratic (B) equations using natural logarithmic terms and back transformation thereafter.

Table A2 Results for the linear and quadratic equations fitted for body weights (kg) and body nitrogen content relative to live body weight (g/kg LBW) by period for all weight classes.

	Obs.	Parameters			Statistics				
	n	a	b	c	RMSE	R ²	Variance	Normality	Log likelihood
lnN = a + b*lnLBW									
1950-1969	50	3.078***	1.009***		0.10	0.99	0.04	0.28	47.1
1970-1989	190	3.097***	1.015***		0.10	0.99	0.26	0.29	161.3
1990-2009	190	3.238***	0.984***		0.10	0.99	0.51	0.32	175.6
2010-2024	130	3.095***	1.030***		0.08	0.99	<.001	0.04	151.6
1990-2024	320	3.178***	1.004***		0.09	0.99	0.00	0.00	307.3
lnN = a + b*lnLBW + c*(lnLBW) ²									
1950-1969	50	2.984***	1.095***	-0.014	0.09	0.99	0.06	0.42	48.1
1970-1989	190	3.031***	1.064***	-0.008	0.10	0.99	0.47	0.16	162.2
1990-2009	190	3.144***	1.046***	-0.009	0.10	0.99	0.44	0.48	176.5
2010-2024	130	2.798***	1.238***	-0.032***	0.06	1.00	0.46	0.32	185.6
1990-2024	320	2.957***	1.1525***	-0.0224***	0.09	0.99	0.41	0.02	322.5

See Table 1.

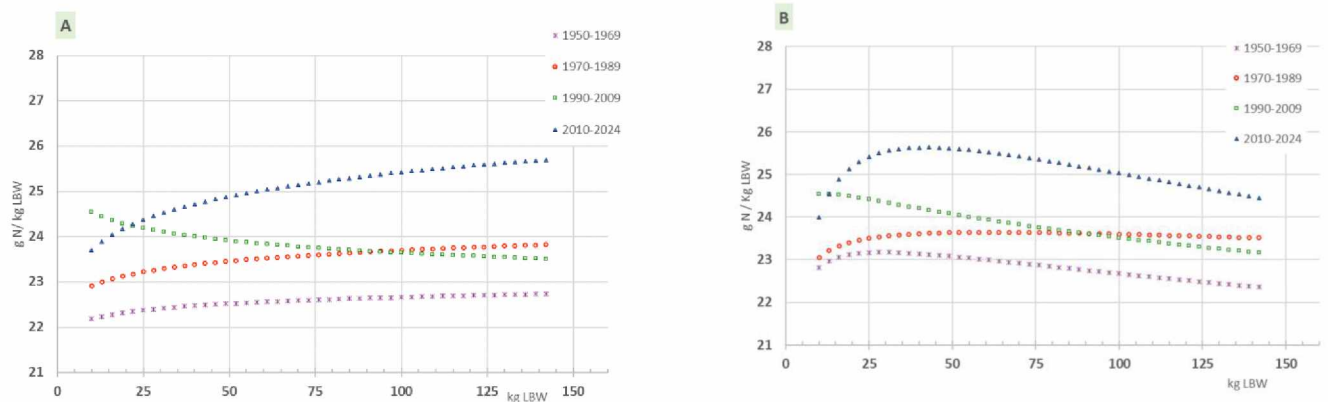


Figure A2 Body content of N per kg of live body weight (LBW) and by period estimated trough linear (A) and quadratic (B) equations using natural logarithmic terms and back transformation thereafter.

Table A3 *Body phosphorous content (g/kg) calculated for live body weight (LW) using linear allometric equations for each period based on the same period (table A1).*

LBW, kg	1950-1969	1970-1989	1990-2009	2010-2024
1.5	5.27	5.02	4.71	5.11
5	5.13	5.06	4.64	5.15
10	5.05	5.09	4.60	5.17
15	5.00	5.10	4.57	5.18
25	4.94	5.12	4.54	5.20
45	4.88	5.14	4.51	5.21
65	4.84	5.15	4.49	5.23
85	4.81	5.16	4.47	5.23
110	4.78	5.17	4.46	5.24
120	4.77	5.17	4.45	5.25
125	4.76	5.17	4.45	5.25

Table A4 *Body nitrogen content (g/kg) calculated for live body weight (LW) using quadratic allometric equations for each period based on the same period (table A2).*

LBW, kg	1950-1969	1970-1989	1990-2009	2010-2024
1.5	20.5	21.2	23.6	18.0
5	22.2	22.5	24.4	22.2
10	22.8	23.1	24.5	24.0
12	22.9	23.2	24.5	24.4
25	23.2	23.5	24.4	25.4
45	23.1	23.6	24.1	25.6
65	23.0	23.6	23.9	25.5
85	22.8	23.6	23.7	25.2
110	22.6	23.6	23.4	24.9
120	22.5	23.6	23.3	24.8
125	22.5	23.6	23.3	24.7

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