sustainability

MDPI

Article

The Nutrient Content of Litter and Manure from Different Poultry Systems—Updating and Establishing the Nutrient Profile

M. Elizabeth E. Ball [1,*], Lavinia P. Wright [1], Keith Wilson [2], Harold Richmond [3], Richard Cummings [4], Sam Smyth [5], Mark Davison [6], Keiron Forbes [7], Jonathan Thompson [8] and Paul Bryson [9]

1 Livestock Production Branch, Agri-Food and Biosciences Institute, Hillsborough, Co. Down BT26 6DR, Northern Ireland, UK; lavinia.wright@afbini.gov.uk
2 Moy Park Ltd., 73 Killyman Road, Dungannon, Co. Tyrone BT71 6LN, Northern Ireland, UK; keith.wilson@moypark.com
3 Skea Eggs Ltd., 15 Mullaghfurtherland Road, Dungannon, Co. Tyrone BT70 2UA, Northern Ireland, UK; harold@skeaeggs.com
4 Ready Eggs Ltd., 116 Crom Road, Milltate, Lisnaskea, Co. Fermanagh BT92 0BN, Northern Ireland, UK; richardcummings@readyeggproducts.com
5 John Thompson and Sons Ltd., 39 York Road, Belfast, Co. Antrim BT15 3GW, Northern Ireland, UK; sam.smyth@thompson.co.uk
6 Ballygarvey Eggs, 108 Ballygarvey Road, Ballymena, Co. Antrim BT43 7JX, Northern Ireland, UK; md@ballygarvey.com
7 Robert Clarke Keady Ltd., 105 Darkley Road, Keady, Co. Armagh BT60 3AY, Northern Ireland, UK; keiron@agriresearch.co.uk
8 Farmlay Eggs, 58a Hamiltownsbawn Road, Armagh, Co. Armagh BT60 1HW, Northern Ireland, UK; jonathan@farmlayeggs.co.uk
9 Glenshane Farm Fresh Eggs, 15 Tullheran Road, Maghera, Co. Londonderry BT46 5JQ, Northern Ireland, UK; info@glenshaneeggs.com
* Correspondence: elizabeth.ball@afbini.gov.uk; Tel.: +44-(0)-2892682484

Abstract: Representative samples of litter and/or manure from 12 of the most common poultry systems were collected and analysed to provide an accurate nutrient profile from each system. For many systems (turkeys, broilers under indirect heating systems, and pullets), there were no previous values with which to compare composition, but for other systems (broiler breeders and layers), nitrogen and phosphate content were lower as a result of changes in diet and advancements in genetics and management. Nitrogen and phosphate output per 1000 birds was calculated for each system using analysed values for nitrogen and phosphate and measured litter/manure output. Due to a lack of data, it was not possible to compare the nutrient profile of all systems with published values, but where this was possible, some important differences were apparent. For example, the nitrogen and phosphate contents of BB (0–18 weeks) litter were 31% lower and 73% higher than current standard values. Similar differences were also observed for BB (18–60 weeks) (26% lower in nitrogen and 51% higher in phosphate). Turkey litter was found to contain 14% less nitrogen and 37% less phosphate than standard values. Litter from pullet systems contained higher levels of DM (72%), nitrogen, and phosphate than standard values. Litter from free range laying systems also contained higher DM (46%), nitrogen, and phosphate than standard values. This information will be useful in updating environmental legislation and ensuring that poultry producers are able to calculate accurate nutrient management plans for their enterprises. This study also established relations between litter/manure dry matter (DM) and nutrient profile, meaning that this simple measured parameter can be used to predict nutrient profile. The strongest relations were observed between DM and N (R^2 = 0.65), DM and phosphate (R^2 = 0.53), and DM and MgO (R^2 = 0.69). The weakest relation was observed between DM and WSP content (R^2 = 0.21), although still significant (p = 0.046). It was concluded that it is necessary to consider the relation within individual systems when using DM as a predictor of nutrient profile rather than using a combined system approach. The water-soluble phosphorus (WSP) content of litter/manure was determined and a baseline was established for each production system. It was also shown that DM is positively related ($p < 0.05$) to WSP content. This will be important for future legislative compliance based on the WSP content of litter/manure.

Citation: Ball, M.E.E.; Wright, L.P.; Wilson, K.; Richmond, H.; Cummings, R.; Smyth, S.; Davison, M.; Forbes, K.; Thompson, J.; Bryson, P. The Nutrient Content of Litter and Manure from Different Poultry Systems—Updating and Establishing the Nutrient Profile. *Sustainability* **2024**, *16*, 6633. https://doi.org/10.3390/su16156633

Academic Editor: Alexandros Theodoridis

Received: 28 May 2024
Revised: 2 July 2024
Accepted: 31 July 2024
Published: 2 August 2024

Keywords: poultry; litter; manure; nitrogen; phosphate

1. Introduction

It is of importance to quantify the actual nutrient profile of litter and manure from different production systems to ensure accurate nutrient balances on- and off-farm, reduce environmental impact, and calculate nutrient content for either land application or anaerobic digestion. While land application remains the primary means of using litter and manure globally, production from intensive systems often exceeds the local crop requirements and the potential for oversupply is high. To prevent over-application to land from poultry litter and manure and other livestock production, various regulations are in place within the European Union, namely, the Nitrates Directive [1] (Directive 91/676/EEC) and the Integrated Pollution Prevention Control Directive (IPPC) [2] (Directive 96/1/EC). These directives place limitations on land application based on the nutrient content of litter and manure. However, the standard published values for litter and manure nutrient content are almost all based on historic work of more than 20 years ago and do not take into account the changes in genetics, management, and diet formulations which have occurred in recent years. Previous work by this group [3] has shown that the values for dry matter (DM) and phosphorus (P) of standard broiler litter were significantly different from those published and used in standard regulations [4,5], and therefore revised values were included in updated legislation for Northern Ireland [6]. However, there are many production systems within the poultry sector and while it is recognised that the nutrient contents of litter and manure from different production systems are substantially different, this is not reflected in the current regulations where there are only values quoted for N and P for layers, broilers, broiler breeders, and turkeys. No distinction is made between laying hens housed under free range systems, colony systems, or multi-tier free range systems. Similarly, no distinction is made between different production stages of broiler or of turkey production. While there are up to date values for the nutrient content of broiler litter under direct heating systems [3], there are no values specific to indirect heating broiler production systems. In order to ensure that the application of litter and manure is matched to crop requirements, to optimise their use as organic fertiliser, and also to be within legislative limits, it is necessary to quantify the nutrient content of litter and manure from modern production systems.

As water soluble P is the actual polluting agent per se rather than total P, many states in the USA regulate P land application using WSP, and it is highly likely that Europe/UK will also move to regulate P using WSP. A high correlation (98%) between WSP content and the amount of P run-off from the soil has been reported by [7]. It is therefore important to determine the amount in manure and litter to provide information for any future legislative requirement [8]. Furthermore, Refs. [3,9] both reported that WSP content of broiler litter was inversely related to DM content, and it is necessary to investigate this relation further to reduce the environmental footprint of poultry production. In addition, the widespread use of phytase has been instrumental in reducing the total P content of diets and hence the total P content of litter/manure, but there is some controversy in the literature on the effect of phytase on WSP content. Some researchers report that phytase increases WSP [8,10] while other researchers report that phytase decreases WSP content [11,12]. To the authors' knowledge, this is the first study in Europe to determine the WSP content and WSP–total P content of poultry litter/manure from several commercially important poultry production systems.

The aim of this study was to determine the nutrient profile of litter/manure and to determine the WSP content and the WSP–total P ratio of litter/manure from 12 commercially important poultry production systems: broiler breeders (0–18 weeks and 18–60 weeks), free range broilers (0–28 d, 28 d–finish, and 0 d–finish), broilers under indirect heating systems, turkeys (0–6 weeks and 6 weeks–finish), pullets, layers in single-tier free range systems, layers in multi-tier free range systems, and layers in housed systems.

2. Materials and Methods

Twenty units from each production system were selected as representative of each system. Table 1 summarises the production details for each system. The required sample number (*n* = 20 units) was calculated from a power analysis of the variance within the raw dataset of Foy et al. [3] as the number required to ensure sufficient replication. Samples of litter were collected according to Foy et al. [3] and based on the protocol described by Tasistro et al. [13]. Five composite samples were collected from each unit during clear-out. The litter was pushed to one end of the house and removed using a tractor fitted with a loader bucket or a telescopic handler. Litter from the bucket was sampled at five equal intervals throughout the clear-out period to produce five composite samples from the unit. Each composite sample consisted of ten hand grab samples that were mixed together thoroughly to give a 1 kg sample taken in a labelled plastic bag. On the day of collection, the samples were transferred to the Agri-Food and Biosciences Institute (AFBI) and frozen until required for analysis.

Table 1. Production details for the different production systems.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Production period (d)	126	294	28	28	56	42	42	56	112	406	406	406
Intake (kg/bird)	7.4	48.3	1.0	4.0	5.0	3.6	7.7	15.7	61.0	48.7	47.7	47.1
Average feed N content (g/kg) *	32.1	26.4	31.6	26.4	28.6	32.3	38.3	27.5	27.2	26.9	24.4	24.4
Average feed P content (g/kg) *	5.3	4.5	5.2	4.1	4.7	5.5	7.6	5.1	6.9	5.1	4.5	4.5
Start weight (kg)	0.042	1.33	0.03	0.87	0.03	0.042	0.18	2.5	0.035	1.35	1.35	1.33
End weight (kg)	2.17	3.96	0.87	2.2	2.2	2.18	2.5	11.4	1.35	1.90	1.90	1.9
Egg production	N/A	172	N/A		N/A	N/A	N/A	N/A	N/A	320	342	342
Egg weight (g)	N/A	64	N/A		N/A	N/A	N/A	N/A	N/A	63	62	64

1 = broiler breeders 0–18 weeks; 2 = broiler breeders 18–60 weeks; 3 = free range broilers 0–28 d; 4 = free range broilers 28 d–finish; 5 = free range broilers 0 d–finish; 6 = broilers under indirect heating systems; 7 = turkeys 0–6 weeks; 8 = turkeys 6 weeks–finish; 9 = pullets; 10 = layers in single-tier free range systems; 11 = layers in multi-tier free range systems; and 12 = layers in housed systems. * Average N and P values for feed based on internal analysis by feed companies.

Samples from colony systems and multi-tier free range layer systems were collected throughout the production period (24–74 weeks of age) at 10-week intervals. The samples that were taken were not subject to a prolonged storage period in-house and therefore were not subject to any composting. On each sampling occasion, five samples were taken throughout the house and transferred to AFBI to be frozen until all samples were collected at 74 weeks. At the end of the sampling period, the samples were thawed, one sample from each sampling week was mixed to form the first composite sample, one sample from each sampling week was mixed to form the second composite sample, and this was continued until a total of five composite samples were produced for each unit for analysis.

For analyses, samples were thawed and DM, N, and WSP content were determined on a fresh sub-sample according to standard procedures [14]. A sub-sample of each composite sample was oven-dried at 80 °C and milled through a 1 mm screen to determine P, Mg, and K contents. The samples were analysed for P using atomic spectroscopy (Perkin Elmer Flow Injection Analyser, Model FIAS 300), with the measurement of the resultant molybdenum blue complex conducted at 700 nm (Perkin Elmer Lambda 2 Spectrophotometer, Perkin, MA, USA). Mg and K were determined via a Perkin Elmer Atomic Absorption Spectrophotometer (Model 2380). The composite samples were analysed singly, with duplicate analysis being performed every tenth sample [15]. The results of the five composite samples were averaged to give one value per production unit. The values for P, K, and Mg were converted to phosphate (P_2O_5), potash (K_2O), and magnesium oxide (MgO) using the conversion factors of 2.2915, 1.2047, and 1.6581, respectively.

Statistics were performed on the data from each production system to determine minimum, mean, maximum, and standard deviation. Where possible, data from each production system were compared with published values. In order to take account of differences in DM, values were standardised to a common DM to compare with published values. To standardise to a common DM, regression analyses were conducted with nutrient content (WSP, N, phosphate, potash, and MgO) regressed against DM. Linear, quadratic, and cubic regressions were fitted and residuals recorded to check the accuracy of the fitted models. This was completed for each production system separately and the strongest relations presented. Obvious outliers were excluded from the datasets.

Litter/manure quantity from each unit (if practically possible) was also weighed at clear-out, with each load being weighed at local weighbridge facilities. The amount of litter/manure produced per 1000 birds was then calculated. If the actual weighing of litter/manure was not possible for a sufficient number of units in each production system, litter/manure quantity was calculated using assumptions from published sources. Where relevant, this will be discussed in the appropriate results section.

3. Results and Discussion

3.1. Nutrient Content of Litter/Manure

Tables 2–4 present the nutrient content and amount of litter or manure produced from broiler, turkey, and egg production systems. The minimum, mean, and maximum value and standard deviation for each parameter are shown. The tables show the variance within and between production systems for all parameters. As this is the first study in the British Isles to investigate the nutritive value and variability of litter/manure from different systems, it is not possible to compare some systems directly with previously published values as data only are available for broilers and laying hens. The variability within all systems is quite wide and reflects the difficulty in achieving consistency in litter/manure across sites even when under the same management regime. However, the number of units sampled from each system (n = 20) was sufficient to take account of site variability and hence enable the use of mean values to quantify the nutrient profile of the litter/manure. Furthermore, the variability is in line or lower than that reported previously for broiler, turkey, or laying hen litter or manure [3,5,16,17].

The mean values for each system, the proportion of P:N, and the amount of P and N produced in litter/manure are summarised in Table 5. Where possible, comparisons have been made with values from similar work [5] and historic and current Nutrient Action Programmes [6,9]. A different approach to presenting the nutrient content of poultry litter/manure was taken by [17] to produce the nutrient profile of litter/manure for RB209 [5]. These authors did not split production systems into categories, and the nutrient profile of litter/manure was calculated based on regressions with DM for all production systems, combined into one dataset to give one set of values for all poultry litter/manure. They evaluated 31 layer manure samples and 48 broiler/turkey samples and used the combined dataset to determine regression relations with DM. The linear relations observed between DM and other nutrients were all significant ($p < 0.001$) and these can be used to calculate nutrient content at a given DM. Therefore, while RB209 [5] does not have specific categories, the known DM of litter/manure determined in this current study can be used to calculate values to compare with the RB209 publication [5].

Table 2. Litter quantity per 1000 birds and nutrient composition of litter (g/kg fresh weight) for the broiler production systems.

	DM (%)	Nitrogen (g/kg)	WSP (g/kg)	Phosphate (g/kg)	Potash (g/kg)	MgO (g/kg)	Total Litter Output (t/1000)
Broiler breeders 0–18 weeks (System 1)							
Minimum	47.0	14.2	2.8	23.2	17.5	5.5	2.4
Mean	**55.0**	**17.5**	**3.5**	**27.1**	**21.3**	**6.5**	**3.0**
Maximum	68.8	22.2	4.2	33.8	25.3	8.6	3.5
SD	7.23	2.21	0.41	3.15	2.11	0.85	0.37
Broiler breeders 18–60 weeks (System 2)							
Minimum	47.1	16.6	2.5	16.0	17.4	4.4	12.0
Mean	**59.7**	**20.7**	**3.2**	**25.3**	**23.2**	**6.6**	**14.7**
Maximum	72.5	27.0	3.7	31.5	26.5	7.7	18.9
SD	6.82	3.08	0.34	4.56	2.89	0.97	1.91
Free range broilers 0–28 d (System 3)							
Minimum	52.8	25.3	1.8	13.1	13.9	3.7	0.45
Mean	**64.6**	**34.5**	**2.8**	**18.9**	**18.3**	**5.0**	**0.53**
Maximum	75.3	40.1	4.1	24.2	24.1	7.1	0.63
SD	7.7	4.4	0.7	2.67	2.94	0.86	0.06
Free range broilers 28 d–finish (System 4)							
Minimum	38.9	20.9	1.8	11.0	11.3	3.0	0.83
Mean	**56.4**	**28.5**	**2.9**	**16.0**	**16.5**	**4.6**	**1.58**
Maximum	75.6	37.0	3.9	22.5	21.0	6.1	2.03
SD	9.52	4.97	0.46	2.82	2.73	0.85	0.31
Free range broilers 0 d–finish (System 5)							
Minimum	44.8	21.7	2.0	11.4	12.5	3.4	1.4
Mean	**57.2**	**26.4**	**2.8**	**15.4**	**19.1**	**5.3**	**1.7**
Maximum	70.1	32.2	3.7	20.7	24.5	7.2	2.2
SD	7.682	3.229	0.361	2.890	3.720	1.128	0.23
Broilers under indirect heating systems (System 6)							
Minimum	60.2	28.7	2.3	13.2	19.7	6.1	0.92
Mean	**72.2**	**33.8**	**2.8**	**16.1**	**22.1**	**7.0**	**1.02**
Maximum	82.2	39.0	3.7	19.2	23.4	8.1	1.21
SD	5.97	3.26	0.39	1.60	1.18	0.51	0.085

SD = standard deviation.

Table 3. Litter quantity per 1000 birds and nutrient composition of litter (g/kg fresh weight) for the turkey production systems.

	DM (%)	Nitrogen (g/kg)	WSP (g/kg)	Phosphate (g/kg)	Potash (g/kg)	MgO (g/kg)	Total Litter Output (t/1000)
Turkeys 0–6 weeks (System 7)							
Minimum	49.1	17.1	2.2	10.2	13.2	2.9	*
Mean	**62.0**	**26.6**	**3.8**	**17.8**	**21.5**	**4.9**	**3.9**
Maximum	72.6	36.9	4.8	23.8	26.6	6.7	*
SD	8.05	5.72	0.66	4.20	4.64	1.09	*
Turkeys 6 weeks–finish (System 8)							
Minimum	40.4	17.5	1.9	8.1	10.9	2.5	9.5
Mean	**58.5**	**24.8**	**3.1**	**13.7**	**15.3**	**3.8**	**12.3**
Maximum	73.3	38.5	4.9	22.8	20.4	5.3	17.4
SD	8.46	5.12	0.66	3.30	2.66	0.79	1.92

* Litter/manure quantity not weighed from these production systems—calculated using intake data. SD = standard deviation.

Table 4. Litter/manure quantity per 1000 birds and nutrient composition of litter/manure (g/kg fresh weight) for the layer production systems.

	DM (%)	Nitrogen (g/kg)	WSP (g/kg)	Phosphate (g/kg)	Potash (g/kg)	MgO (g/kg)	Total Litter/Manure Output (t/1000)
Pullets (System 9)							
Minimum	53.2	26.0	2.4	22.4	19.5	5.8	*
Mean	**72.3**	**32.7**	**4.2**	**27.6**	**23.8**	**6.9**	**2.3**
Maximum	83.5	41.1	7.0	34.7	27.8	7.6	*
SD	8.18	4.64	1.33	3.85	2.52	0.45	*
Layers in single-tier free range systems (System 10)							
Minimum	35.7	13.4	2.0	11.8	12.8	3.3	13.9
Mean	**46.2**	**18.8**	**2.60**	**17.3**	**18.9**	**5.1**	**17.3**
Maximum	68.7	32.3	3.3	24.1	24.8	7.9	22.0
SD	9.50	4.51	0.39	3.50	3.88	1.45	*
Layers in multi-tier free range systems (System 11)							
Minimum	26.5	13.8	1.1	7.2	7.5	2.0	*
Mean	29.5	16.7	1.6	8.7	10.4	2.7	31.9
Maximum	36.6	19.5	2.3	11.2	14.9	3.8	*
SD	2.57	1.70	0.37	1.12	1.51	0.50	*
After storage	**32.3**	**15.6**	**ND**	**11.6**	**16.6**	**3.7**	**25.3 (weighed)**
Layers in housed systems (System 12)							
Minimum	25.0	15.1	1.0	6.7	8.0	1.9	*
Mean	28.4	16.5	1.6	8.0	9.6	2.5	33.5
Maximum	32.3	19.0	2.2	9.4	11.3	3.2	*
SD	1.69	1.30	0.37	0.8	0.94	0.37	
After storage	**31.1**	**15.4**	**ND**	**10.7**	**15.2**	**3.4**	**29.0 (weighed)**

* Litter/manure quantity not weighed from these production systems—calculated using intake data. SD = standard deviation, ND = not determined.

Table 5. The litter/manure, nitrogen, and phosphorus output and the nutrient profile of litter from different systems.

	DM (%)	Nitrogen (g/kg)	WSP (g/kg)	Phosphate (g/kg)	Potash (g/kg)	MgO (g/kg)	Total Litter/Manure Output (t/1000)	Proportion of Total P/Total N	N Produced in Litter/Manure (kg/1000/week)	P Produced in Litter/Manure (kg/1000/week)
Broiler breeder 0–18 weeks (System 1)	55.0	17.5	3.5	27.1	21.3	6.5	3.0	0.27	2.9	2.0
Broiler breeder 18–60 weeks (System 2)	59.7	20.7	3.2	25.3	23.2	6.6	14.7	0.53	7.2	3.9
Free range broilers 0–28 d (System 3)	64.6	34.5	2.8	18.9	18.3	5.0	0.5	0.24	18.6	4.4
Free range broilers 28 d–finish (System 4)	56.4	28.5	2.9	16.0	16.5	4.6	1.6	0.24	45	11.0
Free range broilers 0 d–finish (System 5)	57.2	26.4	2.8	15.4	19.1	5.3	1.7	0.25	44.9	11.4
Broilers under indirect heating systems (System 6)	72.2	33.8	2.8	16.1	22.1	7.0	1.0	0.21	33.8	7.0
Turkeys 0–6 weeks (System 7)	62.0	26.6	3.8	17.8	21.5	4.9	3.9	0.29	103.9	30.3
Turkeys 6 weeks–finish (System 8)	58.5	24.8	3.1	13.7	15.3	3.8	12.3	0.24	305	73.8
Pullets (System 9)	72.3	32.7	4.2	27.6	23.8	6.9	2.3	0.37	4.7	1.7
Layers in single-tier free range systems (System 10)	46.2	18.8	2.6	17.3	18.9	5.1	17.3	0.40	5.4	2.2
Layers in multi-tier free range systems—FRESH (System 11)	36.6	19.5	2.3	11.2	14.9	3.8	31.9	0.23	9.2	2.1
Layers in multi-tier free range systems—STORED (System 11)	32.3	15.6	ND	11.6	16.6	3.7	25.3 (weighed)	0.32	6.8	2.2
Layers FR multi-tier free range systems—LITTER (System 11)	46.2	18.8	2.6	17.3	18.9	5.1	2.0	0.40	0.65	0.3
Layers in housed systems—FRESH (System 12)	28.4	16.5	1.6	8.0	9.6	2.5	33.5	0.21	9.51	2.0
Layers in housed systems—STORED (System 12)	31.1	15.4	ND	10.7	15.2	3.4	29.0 (weighed)	0.30	7.7	2.3

In comparison with [5], N content in litter from broiler breeders (0–18 weeks) as analysed in this study is lower (17.5 vs. 25.5 g/kg) and phosphate content is considerably higher (27.1 vs. 15.7 g/kg). This can be explained by the fact that only layer and broiler/turkey litter and manure were included in the study of the RB209 [5] dataset, and broiler breeder diets contain different levels of nutrients than layers, broilers, and turkey diets. There are very few published studies where broiler breeder litter from the rearing phase (0–18 weeks) has been quantified. Until the current work was conducted, there was no category for this production system in the Nutrient Action Plan for NI apart from an historic figure for N of 21 kg/1000 birds/week and for P of 7.6 kg/1000 birds/week for broiler breeders 18–60 weeks. These historic values overestimated N and P outputs, which are substantially reduced due to an accurate quantification of the quantity of litter produced and the accurate profiling of the nutrients within the litter. These amendments and the inclusion of additional categories for broiler breeders mean that producers can now properly plan for litter storage and disposal.

As for the broiler breeder rearing category (0–18 weeks), there is very little information available in the literature to enable comparison with the values obtained for broiler breeders in the layer phase (18–60 weeks). However, some researchers in the USA have published values for DM, P, and WSP. Casteel et al. [9] analysed litter from broiler breeders at 61 weeks of age and reported values for DM, P, and WSP of 59%, 17.3 g/kg, and 3.7 g/kg, respectively. In addition, Maguire et al. [18] evaluated litter from broiler breeders from 22 to 64 weeks and on average found DM, P, and WSP to be 56%, 14.0 g/kg, and 0.66 g/kg, respectively. The values reported in these studies are not directly comparable to what was observed in the current study as they were specifically designed to influence litter P and WSP content through dietary means and were conducted using USA genetics and feed, and under non-commercial conditions. Nonetheless, they are a useful comparison with the values reported in this study and support the findings in relation to DM, P, and WSP.

In comparison with RB209 [5], the values observed in this study for litter from broiler breeder layer systems (18–60 weeks) are lower in nitrogen (20.7 vs. 27.8 g/kg) and higher in phosphate (25.3 vs. 16.8 g/kg), with similar amounts of potash (23.2 vs. 20.5 g/kg) and MgO (6.6 vs. 5.9 g/kg). As stated previously, the dataset from RB209 [5] does not include samples specifically from broiler breeder systems (18–60 weeks) and therefore does not fully reflect the nutrient profile of litter from this production system.

Historically, there was no category for free range broilers within the NI Nutrient Action programme regulations prior to this work and values for standard broilers were used. The results of this study have enabled specific recommendations for free range broilers (day-old to death) to be used in updated regulations (2019–2022) [19], but these values are used for all free range broilers and categories need to be created in revised legislation for early- and later stage free range broiler production, i.e., 0–28 d and 28 d–finish. There is good agreement between the recommended revised values for NAP and RB209 [5] values.

The work by Foy et al. [3] evaluated the nutrient content of litter from broiler production systems in 2010 and compared contents with broiler litter from 2004 and from values quoted in the RB209 publication [5], which were the industry standards at that time. It was found that the DM of litter had increased, and phosphate content had decreased primarily as a result of advancements in management, genetics, and nutrition (namely, the use of phytase) between 1994 and 2010. Since 2010, there have been further advancements in the management of broilers, and a large number of producers have installed indirect heating systems, which is thought to increase the DM content of litter and as such may influence litter nutrient profile. The results of this study confirm that indirect heating systems increase the DM of the litter (72 vs. 66%) but with little difference in the other nutrients on a fresh basis (cf. Foy et al. [3]), although overall N and P output/1000 birds/week was reduced due to the lower litter quantity produced. In comparison with RB209 [5], the levels of N, potash, and MgO were very similar but phosphate content was lower for litter in this study (16.1 vs. 19.5 g/kg).

There are few relevant studies with which to compare the profile of turkey litter but within the previous legislation [6], values for the nutrient content of turkey litter were given for the entire production period and also split for male and females turkeys. In consultation with industry, it was decided that the nutrient profile of turkey production should be evaluated for two periods (0–6 weeks and 6 weeks–finish). Previous regulations [5] listed turkey litter as containing 60% DM, 30 g/kg nitrogen, and 25.2 g/kg phosphate (fresh basis), which was similar to that reported by UK researchers [20]. This study found that DM was similar at 62% and 58.5% for the two systems. However, nitrogen and phosphate contents were substantially lower in this study (on average, 25.7 g/kg N and 15.8 g/kg phosphate). These reductions are reflective of the lower crude protein diets in modern rations, increased efficiency, and the use of phytase to lower the use of dietary inorganic phosphorus inclusion. The values in the current study are also lower for N, phosphate, potash, and MgO than what is predicted through regression equations from RB209 [5]. These differences may again be explained by the fact that the dataset from [5] was not specific to turkey litter. While samples collected for RB209 [5] did contain turkey litter, no information was given as to the number of turkey litter samples or what type of system they originated from. The findings of this study have led to a revision of the turkey category within the current regulations [19], and it is proposed to further update the regulations with the 0–6 weeks data.

As for turkeys, the previous regulations [6] did not a specific category listing the nutrient content of litter from pullets (apart from a figure for N and phosphorus of 5.7 kg and 2.1 kg/1000 birds/week, respectively), and as a result of this work, the category has now been included in the current regulations [19]. The actual N content of the litter in this study (32.7 g/kg fresh basis) is higher than that reported by Smith et al. [21] (16 g/kg), [22] (17.3 g/kg), and [23] (17.1 g/kg N). This could be due to the higher levels of N in the diets offered within the current study (on average, 19.5% crude protein). The work by Smith et al. [21] quotes an average CP of 16.5%. The higher N content could also be explained by the high DM recorded in this study (72%). A value of 30% DM was reported by Smith et al. [21], which is unrealistically low for litter-based systems.

The N, potash, and MgO content of the analysed pullet litter in this study was similar to the values quoted by RB209 [5] (Table 5). However, the phosphate content was sustainably higher. This may be explained by the fact that the dataset from RB209 [5] contained no litter samples from pullet production systems, and further highlights the need for separate categories for different production systems.

The previous regulations [6] did have a category listing the nutrient content of output from laying hens, but the values were known to be outdated and not relevant for litter produced from modern production systems. Hen manure was listed as containing 30% DM, 16 g/kg nitrogen, and 13 g/kg phosphate. Through analysis, this study has found that the litter from standard free range laying hens contains higher DM (46%), higher nitrogen (18.8 g/kg), and higher phosphate (17.3 g/kg) on a fresh basis. Ref. [5] quotes higher nitrogen (21 g/kg) and lower phosphate (13.7 g/kg) than what was observed in the current study. The reason for the differences can be attributed to the higher DM and the degree of composting within the litter-based system.

Based on the results of this study, new values are proposed for litter/manure from layers in multi-tier and in housed systems. As can be seen from Table 5, values are presented as fresh or as stored. The majority of previous work on nutrient profiling of hen manure has been based on fresh samples taken from the belt system [5,20], but this takes no account of the composting that will occur during the storage period. In practice, no manure is removed directly from the house and immediately land-spread or immediately transferred to an AD plant. Therefore, to achieve an accurate profile of hen manure from these systems, an analysis of the stored manure must be completed and a degree of composting applied to the figures. This was done in the current study, and it was found that for the stored manure, N levels are similar to litter from single-tier systems but phosphate, potash, and magnesium oxide levels are lower. The differences in phosphate, potash, and magnesium oxide on a fresh basis are due to the lower DM of manure from multi-tier or housed systems (32.3 and 31.1% vs. 46.2% DM). On a dry matter basis, the profile of the manure (apart from nitrogen content) is similar. On a dry matter basis, there is a higher concentration on nitrogen in manure from multi-tier or housed systems, and this is due to a lower level of volatilisation from these systems, thus locking more N into the manure [24].

A criticism of most of the previous reports on the nutrient profile of poultry litter and manure is that few of the studies measured or recorded actual output from the systems, and therefore the output of key nutrients on a per bird or per bird place cannot be calculated. Quite often, legislative standards of outputs are based on historic values whose origin cannot be traced. This study weighed actual output from a number of different units from the different systems. Where this was not possible, manure/litter output was calculated using standard values [21] and through equations which related intake to output. As a result of the more accurate manure/litter output values, the output of key nutrients per 1000 birds was calculated more accurately than many previous studies. This is critical in understanding the contribution of nutrient excretion in manure/litter from the different production systems. The accurate estimation of nutrient excretion in manure/litter can be used to update legislation, and a summary for such purposes is provided in Table 5.

Regression analysis showed significant linear relations between DM content and other nutrients (Tables 6–8). Moderate relations were observed between DM and N (R^2 = 0.65), DM and phosphate (R^2 = 0.53), and DM and MgO (R^2 = 0.69). The weakest relation was observed between DM and WSP content (R^2 = 0.21), although still significant (p = 0.046). On the whole, regression analysis yielded significant ($p < 0.05$) relations with the majority of the nutrients being correlated with DM. However, the slope, intercept, and strength of the relations are different for each system and based on this, it can be concluded that the prediction of nutrient profile from DM for individual systems is feasible but systems should not be combined to produce a generic poultry category. Thus, the method of analysing manure/litter from individual systems as applied in the current study has been justified. Furthermore, the impact of bird age and different dietary nutrients on nutrient output across the different systems means that a comparison between systems is not feasible and again points to the inaccuracy of combining different systems to produce relations to DM.

Table 6. Relation between DM content (%) and nutrient content of litter from broiler production systems.

	Equation	Type	R^2	p Value
Broiler breeders 0–18 weeks (System 1)				
Nitrogen (g/kg fresh)	3.72 + (0.25 × DM)	Linear	0.65	<0.001
WSP (g/kg fresh)	4.98 + (0.03 × DM)	Linear	0.21	0.046
Phosphate (g/kg fresh)	9.19 + (0.32 × DM)	Linear	0.53	<0.001
Potash (g/kg fresh)	10.39 + (0.20 × DM)	Linear	0.42	0.002
MgO (g/kg fresh)	1.11 + (0.10 × DM)	Linear	0.69	<0.001
Broiler breeders 18–60 weeks (System 2)				
Nitrogen (g/kg fresh)	1.90 + (0.31 × DM)	Linear	0.46	0.001
WSP (g/kg fresh)	$-12.59 + (0.50 \times DM - 0.0004 \times DM^2)$	Quadratic	0.21	<0.001
Phosphate (g/kg fresh)	$21.2 + (0.001 \times DM^2)$	Quadratic	0.53	0.011
Potash (g/kg fresh)	14.10 + (0.15 × DM)	Linear	0.42	NS
MgO (g/kg fresh)	$-27.0 + (1.05 \times DM - 0.008 \times DM^2)$	Quadratic	0.69	0.004
Free range broilers 0–28 d (System 3)				
Nitrogen (g/kg fresh)	12.28 + (0.34 × DM)	Linear	0.60	0.009
WSP (g/kg fresh)	$-17.15 + (0.64 \times DM + -0.005 \times DM^2)$	Quadratic	0.12	NS
Phosphate (g/kg fresh)	13.18 + (0.09 × DM)	Linear	0.06	NS
Potash (g/kg fresh)	8.13 + (0.16 × DM)	Linear	0.09	NS
MgO (g/kg fresh)	0.94+ (0.06 × DM)	Linear	0.49	0.016
Free range broilers 28 d–finish (System 5)				
Nitrogen (g/kg fresh)	5.92 + (0.403 × DM)	Linear	0.59	<0.001
WSP (g/kg fresh)	2.14 + (0.01 × DM)	Linear	0.08	NS
Phosphate (g/kg fresh)	13.36 + (0.05 × DM)	Linear	0.02	NS
Potash (g/kg fresh)	3.88 + (0.22 × DM)	Linear	0.62	<0.001
MgO (g/kg fresh)	0.30 + (0.08 × DM)	Linear	0.73	<0.001
Free range broilers 0 d–finish (System 5)				

Table 6. *Cont.*

	Equation	Type	R^2	*p* Value
Nitrogen (g/kg fresh)	11.71 + (0.26 × DM)	Linear	0.33	0.006
WSP (g/kg fresh)	1.97 + (0.014 × DM)	Linear	0.09	NS
Phosphate (g/kg fresh)	3.83 + (0.20 × DM)	Linear	0.25	0.017
Potash (g/kg fresh)	−3.84 + (0.40 × DM)	Linear	0.67	<0.001
MgO (g/kg fresh)	−2.15 + (0.13 × DM)	Linear	0.76	<0.001
Broilers under indirect heating systems (System 6)				
Nitrogen (g/kg fresh)	1.02 + (0.45 × DM)	Linear	0.68	<0.001
WSP (g/kg fresh)	24.79 + (−0.67 × DM + 0.005 × DM^2)	Quadratic	0.70	<0.001
Phosphate (g/kg fresh)	3.16 + (0.18 × DM)	Linear	0.42	0.001
Potash (g/kg fresh)	15.51 + (0.09 × DM)	Linear	0.17	0.041
MgO (g/kg fresh)	3.12 + (0.05 × DM)	Linear	0.36	0.003

Table 7. Relation between DM content (%) and nutrient content of litter from turkey production systems.

	Equation	Type	R^2	*p* Value
Turkeys 0–6 weeks (System 7)				
Nitrogen (g/kg fresh)	−1.25 + (0.45 × DM)	Linear	0.40	0.002
WSP (g/kg fresh)	0.18 + (0.06 × DM)	Linear	0.5	<0.001
Phosphate (g/kg fresh)	−5.70 + (0.38 × DM)	Linear	0.73	<0.001
Potash (g/kg fresh)	−2.43 + (0.39 × DM)	Linear	0.67	<0.001
MgO (g/kg fresh)	−1.60 + (0.10 × DM)	Linear	0.77	<0.001
Turkeys 6 weeks–finish (System 8)				
Nitrogen (g/kg fresh)	3.46 + (0.37 × DM)	Linear	0.445	0.005
WSP (g/kg fresh)	9.36 + (−0.28 × DM + 0.003 × DM^2)	Quadratic	0.551	<0.001
Phosphate (g/kg fresh)	−1.65 + (0.26 × DM)	Linear	0.422	0.001
Potash (g/kg fresh)	2.75 + (0.21 × DM)	Linear	0.431	<0.001
MgO (g/kg fresh)	−0.12 + (0.07 × DM)	Linear	0.479	<0.001

Table 8. Relation between DM content (%) and nutrient content of litter/manure from layer production systems.

	Equation	Type	R^2	*p* Value
Pullets (System 9)				
Nitrogen (g/kg fresh)	136.4 + (−3.37 × DM + 0.026 × DM^2)	Quadratic	0.473	0.002
WSP (g/kg fresh)	9.10 + (−0.068 × DM)	Linear	0.177	NS
Phosphate (g/kg fresh)	22.07 + (0.076 × DM)	Linear	0.026	NS
Potash (g/kg fresh)	17.15 + (0.092 × DM)	Linear	0.090	NS
MgO (g/kg fresh)	4.69 + (0.03 × DM)	Linear	0.257	0.016
Layers in single-tier free range systems (System 10)				
Nitrogen (g/kg fresh)	41.4 + (−1.31 × DM + 0.017 × DM^2)	Quadratic	0.853	<0.001
WSP (g/kg fresh)	1.25 + (0.029 × DM)	Linear	0.470	0.002
Phosphate (g/kg fresh)	3.22 + (0.305 × DM)	Linear	0.662	<0.001
Potash (g/kg fresh)	4.42 + (0.313 × DM)	Linear	0.561	<0.001
MgO (g/kg fresh)	−13.89 + (0.67 × DM + −0.005 × DM^2)	Linear	0.646	<0.001
Layers in multi-tier free range systems (System 11)				
Nitrogen (g/kg fresh)	6.48 +(0.38 × DM)	Linear	0.32	0.009
WSP (g/kg fresh)	−0.52 + (0.07 × DM)	Linear	0.25	0.02
Phosphate (g/kg fresh)	−1.79 + (0.35 × DM)	Linear	0.64	<0.001
Potash (g/kg fresh)	−1.57 + (0.40 × DM)	Linear	0.46	<0.001
MgO (g/kg fresh)	−2.39 + (0.16 × DM)	Linear	0.7	<0.001

Table 8. *Cont.*

	Equation	Type	R^2	*p* Value
Layers in housed systems (System 12)				
Nitrogen (g/kg fresh)	9.69 +(0.24 × DM)	Linear	0.10	NS
WSP (g/kg fresh)	−3.45 + (0.16 × DM)	Linear	0.54	0.001
Phosphate (g/kg fresh)	0.21 + (0.27 × DM)	Linear	0.32	0.028
Potash (g/kg fresh)	5.13 + (0.16 × DM)	Linear	0.08	NS
MgO (g/kg fresh)	−2.47 + (0.17 × DM)	Linear	0.62	<0.001

3.2. Water Soluble Phosphorus (WSP)

As stated in the introduction, this study was the first in the British Isles to determine the WSP content of poultry litter/manure and to further investigate the relation between WSP content and litter/manure DM. Table 9 summarises the WSP content, the ratio of WSP content to total P, and the relation between WSP and litter/manure DM for the 12 main production systems in NI. As the WSP content of litter/manure produced in Northern Ireland has only being quantified for broilers [3], it is impossible to comment on the changes in the WSP content of litter/manure due to dietary, genetic, and management advances. In comparison with Foy et al. [3], broiler litter produced under direct heating systems resulted in lower WSP content (3.2 vs. 3.8 g/kg) and lower WSP–total P content (0.56 vs. 0.29) than conventional broiler litter. Given the relation between WSP content and run-off, this may mean that there is less P run-off from land-spreading litter from broilers under direct heating systems than from litter from conventionally heated broiler production, but this is dependent on crop requirements and soil conditions. The results of this study have established an important baseline for WSP content of litter/manure from several different production systems.

Table 9. Summarised WSP content and relation between WSP and DM content for 12 production systems.

Production System	WSP Content (g/kg)	WSP–Total P	Relation between WSP and DM Content		
			Type	R^2	*p* Value
Broiler breeders 0–18 weeks (System 1)	3.5	0.30	Linear positive	0.21	0.046
Broiler breeders 18–60 weeks (System 2)	3.2	0.29	Quadratic negative	0.21	<0.001
Free range broilers 0–28 d (System 3)	2.8	0.40	Quadratic positive	0.70	<0.001
Free range broilers 28 d–finish (System 4)	2.8	0.42	Linear negative	0.09	NS
Free range broilers 0 d–finish (System 5)	2.8	0.34	Quadratic negative	0.12	NS
Broilers under indirect heating systems (System 6)	2.9	0.42	Linear negative	0.08	NS
Turkeys 0–6 weeks (System 7)	3.8	0.49	Linear positive	0.50	<0.001
Turkeys 6 weeks–finish (System 8)	3.1	0.52	Quadratic positive	0.55	<0.001
Pullets (System 9)	4.2	0.35	Linear negative	0.18	NS
Layers in single-tier free range systems (System 10)	2.6	0.34	Linear positive	0.47	0.002
Layers in multi-tier free range systems—FRESH (System 11)	1.9	0.43	Linear negative	0.25	0.020
Layers in housed systems—FRESH (System 12)	1.8	0.45	Linear negative	0.54	<0.001

As far as the authors are aware, this study is the first to consider the relation between the WSP content and DM of a range of litter/manure samples from different production systems. It is interesting to note that in keeping with other research reports on single production systems [3,9], there is an inverse linear relation between WSP and litter/manure DM for colony layers, multi-tier layers, and free range broilers 28 d–finish only. Other relations are either non-significant, positive, or quadratic in that increasing DM will cause a reduction in WSP content to a certain level and then there will be no further benefit. Our group previously suggested that increasing DM may be a means to reduce the environmental impact of P run-off [3], but the results of the current study indicate that there are other factors involved which influence WSP content more strongly than DM alone. One of the main factors may be the calcium-to-available P ratio in diets, as Leytem et al. [25] reported that it is this ratio that has the greatest influence on WSP content and they showed that it was possible to reduce WSP by 73% by increasing this ratio. Obviously, it is important to supply these nutrients at a ratio to ensure optimum broiler production, health, and welfare, but this work indicates that varying this ratio could be a means of reducing the WSP of litter/manure. The dietary calcium-to-available P ratio was not measured in this study, but it would be useful to determine this ratio and examine the impact on the WSP content of the different litter/manures. Furthermore, future research should focus on the factors influencing WSP content using the baseline values established in this study as a basis for comparison and improvement.

4. Conclusions

This study has profiled the nutrient content of litter/manure from 12 different systems on an individual basis, providing information to update environmental legislation and ensuring the optimum use of litter/manure as an organic fertiliser and/or as a source for anaerobic digestion. The nutrient profiling also will provide poultry producers with accurate values by which they can complete a nutrient management plan for their enterprise, further ensuring compliance with legislation and ultimately improving water quality. This study has also provided a baseline of WSP content of litter/manure from different systems and established the relation between this important polluting nutrient and litter/manure DM.

Author Contributions: Conceptualization, all authors; methodology, M.E.E.B., L.P.W., K.W., S.S., K.F., M.D., J.T., P.B., H.R. and R.C.; writing—original draft preparation, M.E.E.B.; writing—review and editing, all authors; project administration, M.E.E.B.; funding acquisition, M.E.E.B. All authors have read and agreed to the published version of the manuscript.

Funding: This project was funded by the Department of Agriculture, Environment and Rural Affairs, Evidence and Innovation Project 15/04/07 (AFBI Activity Code 48067) and Agri-Food Quest Competence Centre Project 27-05-001 (AFBI Activity Code 49234).

Data Availability Statement: Data are contained within the article.

Acknowledgments: The project was conducted in collaboration with Moy Park Ltd., Skea Eggs Ltd., J Thompson and Sons Ltd., Ready Egg Products, Ballygarvey Eggs, Clarke's of Keady, Farmlay Eggs, and Glenshane Eggs.

Conflicts of Interest: The authors declare no conflict of interest. Ball, M.E.E. and Wright, L.P are employees of the Agri-Food and Biosciences Institute which is a publicly funded non-departmental funded body. Wilson, K., Richmond, H., Cummings R., Smyth, S., Davison, M., Forbes, K., Bryson, P. and Thompson, J. are employees of Moy Park Ltd., Skea Eggs Ltd., Ready Eggs Ltd., John Thompson and Sons Ltd., Ballygarvey Eggs, Robert Clarke Keady Ltd., Glenshane Eggs and Farmlay Eggs respectively. There was no conflict of interests for the companies involved. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Council Directive of 12 December 1991 Concerning the Protection of Waters against Pollution Caused by Nitrates from Agricultural Sources (91/676/EEC) EUR-Lex—31991L0676—EN (europa.eu). Available online: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31991L0676:EN:HTML (accessed on 27 October 2023).
2. Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 Concerning Integrated Pollution Prevention and Control. EUR-Lex—l28045—EN—EUR-Lex (europa.eu). Available online: https://eur-lex.europa.eu/EN/legal-content/summary/integrated-pollution-prevention-and-control-until-2013.html#:~:text=This%20Directive%20(%E2%80%9Cthe%20IPPC%20Directive%E2%80%9D)%20requires%20industrial%20and,preventing%20and%20reducing%20any%20pollution%20they%20may%20cause (accessed on 27 October 2023).
3. Foy, R.H.; Ball, M.E.E.; George, J. Assessing the changes in the composition of broiler litters from commercial poultry units in NI following the adoption of phytase in diets. *Poult. Sci.* **2014**, *93*, 2718–2723. [CrossRef] [PubMed]
4. MAFF. *Fertilizer Recommendations for Agricultural and Horticultural Crops (RB209)*, 6th ed.; Ministry of Agriculture, Fisheries and Food: London, UK; HMSO: London, UK, 1994.
5. AHDB. *Nutrient Management Guide (RB209). Section 2 Organic Materials*; ADHB Publication: Coventry, UK, 2017. Available online: https://ahdb.org.uk/knowledge-library/rb209-section-2-organic-materials (accessed on 31 October 2023).
6. Nitrates Action Programme 2015–2018 and Phosphorus Regulations Guidance Booklet. Available online: https://www.daera-ni.gov.uk/sites/default/files/publications/dard/nap-2015-2018-and-phosphorus-regulations-guidance-booklet-final-may-2016.pdf (accessed on 31 October 2023).
7. Sharpley, A.; Moyer, J. Phosphorus forms in manure and compost and their release during simulated rainfall. *Environ. Qual.* **2000**, *29*, 1462–1469. [CrossRef]
8. Vadas, P.A.; Meisinger, J.J.; Sikora, L.J.; McMurtry, J.P.; Sefton, A.E. Effect of poultry diet on phosphorus in runoff from soils amended with poultry manure and compost. *J. Environ. Qual.* **2004**, *33*, 1845–1854. [CrossRef] [PubMed]
9. Casteel, S.N.; Maguire, R.O.; Israel, D.W.; Crozier, C.R.; Brake, J. Broiler breeder manure phosphorus forms are affected by diet, location, and period of accumulation. *Poult. Sci.* **2011**, *90*, 2689–2696. [CrossRef] [PubMed]
10. De Laune, P.B.; Moore, P.A., Jr.; Carman, D.C.; Daniel, T.C.; Sharpley, A.N. Development and validation of a phosphorus index for pastures fertilized with animal manure. In Proceedings of the International Symposium Addressing Animal Production & Environmental Issues, Raleigh, NC, USA, 1–5 October 2001.
11. Applegate, T.J.; Joern, B.C.; Nussbaum-Wagler, D.L.; Angel, R. Water-soluble phosphorus in fresh broiler litter is dependent upon phosphorus concentration fed but not on fungal phytase supplementation. *Poult. Sci.* **2003**, *82*, 1024–1029. [CrossRef]
12. McGrath, J.M.; Sims, J.T.; Maguire, R.O.; Saylor, W.W.; Angel, R. Modifying broiler diets with phytase and vitamin D metabolite (25-OH D3): Impact on phosphorus in litter, amended soils, and runoff. *J. Environ. Qual.* **2010**, *39*, 324–332. [CrossRef] [PubMed]
13. Tasistro, A.S.; Kissel, D.E.; Bush, P.B. Sampling broiler litter: How many samples are needed? *J. Appl. Poult. Res.* **2004**, *13*, 163–170. [CrossRef]
14. AOAC. *Official Methods of Analysis of the Association of Official Analytical Chemists*, 15th ed.; Association of Official Analytical Chemists: Arlington, VA, USA, 1990.
15. Peters, J.; Combs, S.M.; Hoskins, B.; Jan, J.; Kovar, J.L.; Watson, M.E.; Wolf, A.M.; Wolf, N. *Recommended Methods of Manure Analysis (A3769)*; University of Wisconsin-Extension: Madison, WI, USA; Cooperative Extension Publishing: Madison, WI, USA, 2003; ISBN 978-1-946135-86-5.
16. UKPIR01: Methods of Disposal or Processing of Waste Streams from Intensive Livestock Production in Scotland and Northern Ireland, May 2005. Final Report. Available online: https://www.sniffer.org.uk/Handlers/Download.ashx?IDMF=1d85152f-be6c-4d8a-bbc3-e4ec6a9dfa54 (accessed on 12 November 2010).
17. Williams, J.; Munro, D.; Sagoo, L.; Nicholson, F. *Review of Guidance on Organic Manure Nutrient Supply in the "Fertilizer Manual (RB209)*; AHDB Research Review No. 3110149017; Agriculture and Horticulture Development Board: Coventry, UK, 2016.
18. Maguire, R.O.; Plumstead, P.W.; Brake, J. Impact of diet, moisture, location, and storage on soluble phosphorus in broiler breeder manure. *J. Environ. Qual.* **2006**, *35*, 858–865. [CrossRef] [PubMed]
19. Nitrates Action Programme 2019–2022 and Phosphorus Regulations Guidance Booklet. Available online: https://www.daera-ni.gov.uk/sites/default/files/publications/daera/20.21.177%20Nutrients%20Action%20Programme%202019-2022%20Guidance%20Booklet%20Final.PDF (accessed on 31 October 2023).
20. Nicholson, F.A.; Chambers, B.J.; Smith, K.N. Nutrient composition of poultry manures in England and Wales. *Bioresour. Technol.* **1996**, *58*, 279–284. [CrossRef]
21. Smith, K.A.; Charles, D.R.; Moorhouse, D. Nitrogen excretion by farm livestock with respect to landspreading requirements and controlling nitrogen losses to ground and surface waters. Part 2: Pigs and poultry. *Bioresour. Technol.* **2000**, *71*, 183–194. [CrossRef]
22. Laursen, B. *Normtal for Husdyrgodning-Revideret Udgave af Rapport nr 28*; Rapport nr 82; Landbrugsministeriet Statens Jordbrugsokonomiske Institut: Copenhagen, Denmark, 1995.
23. Manitoba Agriculture. *Farm Practices Guidelines for Poultry Producers in Manitoba*; Manitoba Agriculture: Winnipeg, MB, Canada, 1995; p. 57.

24. Ricardo Energy and Environment. *Developing New Ammonia Emission Factors for Modern Livestock Housing (Phase 2). Layers, Broilers and Dairy Cattle*; Defra contract AC0123; Department for Environment, Food & Rural Affairs (DEFRA): London, UK, 2013.
25. Leytem, A.B.; Plumstead, P.W.; Magurie, R.O.; Kwanyuen, P.; Brake, J. What aspect of dietary modification in broilers controls litter water-soluble phosphorus: Dietary phosphorus, phytase, or calcium? *J. Environ. Qual.* **2007**, *36*, 453–463. [CrossRef] [PubMed]