Abstract

In this paper, published and some unpublished information on excretion by pigs and poultry is reviewed. Well established relationships between feed and water intake and faecal and urinary output in fattening pigs have been adapted, using modern growth curves and typical commercial feeding practice, to make estimates of excretal output for a range of growing and finishing pigs and, also, breeding sows. Nitrogen (N) outputs were then estimated from typical excretal N content. For poultry, estimates were based on empirical data available from a range of production related studies and, for broilers and turkeys, a metabolic model relating litter output to liveweight, feed inputs and feed conversion.

An alternative approach of estimating N excretion, via N balance calculations, was undertaken for fattening pigs and sows and for the major poultry categories, and provides some validation of the estimated standards, increasing confidence in their application. These standards are now incorporated into the guidelines already in place for Nitrate Vulnerable Zones in England and Wales and in the recently revised Water Code. © 1999 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Pig slurry; Poultry manure; Faeces; Urine; Nitrogen; Nitrate leaching

1. Introduction

The untimely land application of farm manures has been identified as a major source of potential nitrate pollution in England and Wales (Beckwith et al., 1998) and, in some EU member states, legislation has already been introduced to limit the amount of nitrogen (N) from manures that can be spread onto the land. Council Directive 91/676/EEC (Anon, 1991) covers the application of N to the land, including that from animal manures, in an attempt to reduce further pollution and includes the designation of ‘Nitrate Vulnerable Zones’ (NVZs) which are required to be fully implemented by December, 1999.

Pigs and poultry production are estimated to be responsible for a relatively small proportion of the nearly 200 million tonnes of animal excreta arising annually in the UK (around 20% of the 80 million tonnes collected in and around farm buildings; Smith and Chambers, 1995). However, there are number of important centres of production, e.g., in E. Yorks, Notts, Norfolk, Hereford and Worcs., which may also be in or close to NVZs. In such areas, pig and poultry manure production have very important management and environmental implications. Moreover, large production units (pig or poultry) give rise to some environmental concerns wherever they are located and the availability of good information on excreta production is always important.

Published figures for the production of excreta by pigs and poultry vary widely, and as in the case of other livestock (Smith and Frost, 2000), liveweight and productivity, diet and water intake, as well as housing and seasonal weather conditions, are all factors which can influence the total quantity and nutrient content of excreta produced by livestock. This review attempts to collate the available information for pigs and poultry, and based on a critical evaluation of the data, provide best estimates that may then be used as a guideline, e.g.,
for checking general compliance with NVZ limits, or for general planning purposes.

2. Methods

The methodology, including a review of empirical estimates of waste output and nitrogen (N) excretion and a comparison of N excretion by nutrient balance, is outlined in the associated study on the production of excreta in cattle and sheep (Smith and Frost, 2000). Since livestock production systems have changed significantly in recent years, particularly within the poultry industry, it was felt inappropriate to rely on observations more than 10–15 yrs old, which are unlikely to be representative of present day conditions. However, where no well documented, recent information was available, earlier data were included. Examples of the estimation of N excretion by nutrient balance calculations (after Maynard and Loosli, 1969) are detailed for several categories of poultry within the present paper.

It is important to emphasise that the ‘standard’ figures suggested in this review should be seen only as a guideline to assist in general planning. It is possible that specific production units with specialised feeding and management may have levels of waste production and N excretion quite different from these ‘standards’ and have quantitative evidence to support such a position. For example, the potential to reduce N excretion by dietary manipulation has already been clearly demonstrated by Lee et al. (1995a) for growing/finishing pigs. In terms of poultry, dietary protein quantity and quality, and salt level have been shown to affect both broiler litter N content and moisture content, as well as other aspects of broiler production (Tucker and Walker, 1992).

In some cases, data on excretal output, including N, were drawn together from a number of literature sources and have been used to provide mean estimates of output or to examine relationships between excretal output and animal liveweight; summaries of the source data are not presented in this paper but are available on request from the authors.

3. Results and discussion

3.1. Pigs

Feed quality and level, feeding regime, water consumption, animal size and building environment all impact upon the nutrient content and output volume of pig excreta.

3.1.1. Growing and fattening pigs

A comprehensive study on waste production from fattening pigs was carried out by O’Callaghan et al. (1971), in which daily faecal and urinary production from pigs kept individually, in crates or in groups in pens, were measured over the liveweight range 20–90 kg. The results demonstrated a close linear relationship between feed and water intake and the production of excreta. This study has provided a reliable basis for estimating piggery waste output in the past (e.g., Anon, 1989) and the information has been incorporated into published advice on the management and utilisation of manures (MAFF, 1994).

The crate studies of O’Callaghan et al. (1971), with daily assessments of excretal output averaged on a weekly basis, provided the most consistent results (Table 1). In this review the relationship between floor feeding intake (ad lib water) and excretal output has been used to estimate excretal output over the growth period for a range of growing and fattening pigs:

\[ y = 0.562x + 0.092 \quad (r = 0.817). \]  

The timescale for these estimates is based on a modern growth curve (Cotswold Pig Development Company, 1995) and assumed feed inputs are typical of current, commercial practice. The resulting estimated daily excretal production from meal fed pigs, over a period of 3–23 weeks (¼7–105 kg liveweight), is shown in Fig. 1; calculations restricted to specific age and liveweight ranges were then used to estimate excretal outputs for various classes of growing and finishing pigs (Table 2).

Unpublished data from independent feeding experiments on fattening pigs, at ADAS Terrington

<table>
<thead>
<tr>
<th>Feeding regime water:meal ratio</th>
<th>Equation of line of best fit $b$</th>
<th>Correlation coefficient ($r$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ad lib water $c$</td>
<td>$y = 0.562x + 0.092$</td>
<td>0.817</td>
</tr>
<tr>
<td>2.76:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulated pipeline feed</td>
<td>$y = 0.563x + 0.098$</td>
<td>0.955</td>
</tr>
<tr>
<td>2.5:1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simulated pipeline feed</td>
<td>$y = 0.717x - 0.263$</td>
<td>0.980</td>
</tr>
<tr>
<td>4.0:1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Based on weekly measurements on groups of animals in crates.

* Where $y =$ total excretal output (kg/day); $x =$ total intake of water + meal (kg/day).

* Simulated floor feeding.
Kay (1989), provide some validation of the approach; slurry outputs, measured in these experiments over 7 separate periods between 31 and 97 kg liveweight, are plotted in Fig. 1 and suggest reasonable agreement with predicted slurry outputs. Brooks and Carpenter (1989), emphasised the importance of adequate water intake, but pointed out that both intakes and losses can be extremely variable. Estimates of excretal outputs were included in a theoretical water balance for a 60 kg liveweight pig, in good health, maintained in a thermonutral environment, fed ad lib on a well balanced compound diet (2.7 kg = day feed assumed) containing no mineral excesses (i.e., conditions where water demand is likely to be close to minimum). Daily faecal output was estimated at around 1.14 kg (742 ml water loss, with dung at 35% DM) and urine 3.54 l, giving a total 'slurry' output of 4.68 kg, which is slightly higher than the 'model' predicted output of 4.2 kg/day for a 60 kg pig (Fig. 1). The difference between these two estimates can be explained by the feed intake which, at 2.7 kg, from Brooks and Carpenter (1989), is significantly higher than is likely under current practice.

Data from the literature on waste output and slurry N excretion for growing pigs were drawn together and animal liveweight was shown to correlate well with calculated or estimated slurry N output (where waste outputs were quoted over a liveweight range or growth period, the estimates were assumed to relate to the mid-point of the range):

\[
\text{N output} = 0.16 \times LW (\text{kg}) + 1.58
\]
\( (n = 20) \quad (r^2 = 0.80). \]

Estimates of N output, derived from this relationship and indicated in the final column of Table 2, for growing and finishing pigs, agree well with output estimates derived from the O’Callaghan ‘model’, combined with ‘standard’ slurry N content (MAFF, 1994; K Smith, unpublished data) in the case of young growers. Estimates from Eq. (2) are, otherwise, about 20% higher than ‘model’ predictions, though still within the

<table>
<thead>
<tr>
<th>Type</th>
<th>Age (days)</th>
<th>Weight (kg)</th>
<th>Total a feed intake (kg)</th>
<th>Cumulative slurry output b (kg)</th>
<th>Daily slurry output (kg)</th>
<th>Slurry DM (%)</th>
<th>Estimated N output d (kg/yr)</th>
<th>Derived</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weaner</td>
<td>23–52</td>
<td>7–18</td>
<td>17.6</td>
<td>40</td>
<td>1.3</td>
<td>10</td>
<td>3.0</td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td>Grower</td>
<td>53–78</td>
<td>18–35</td>
<td>31.7</td>
<td>69.3</td>
<td>2.67</td>
<td>10</td>
<td>6.1</td>
<td></td>
<td>6.0</td>
</tr>
<tr>
<td>Light cutter</td>
<td>79–139</td>
<td>35–85</td>
<td>115.7</td>
<td>250.1</td>
<td>4.1</td>
<td>10</td>
<td>9.4</td>
<td></td>
<td>11.2</td>
</tr>
<tr>
<td>Baconer/heavy cutter</td>
<td>79–160</td>
<td>35–105</td>
<td>170</td>
<td>366.4</td>
<td>4.5</td>
<td>10</td>
<td>10.3</td>
<td></td>
<td>12.8</td>
</tr>
<tr>
<td>(wet fed)</td>
<td>79–160</td>
<td>35–105</td>
<td>170</td>
<td>587.2</td>
<td>7.2</td>
<td>6</td>
<td>10.3</td>
<td></td>
<td>12.8</td>
</tr>
<tr>
<td>Sow-dry</td>
<td>–</td>
<td>130–220</td>
<td>272.5 c</td>
<td>947 c</td>
<td>8.7</td>
<td>6</td>
<td>19.5</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>Sow-lactation</td>
<td>–</td>
<td>150–225</td>
<td>188.5 c</td>
<td>664 c</td>
<td>18.4</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sow + litter to 25 kg</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>29.7</td>
<td></td>
<td>28.8</td>
</tr>
</tbody>
</table>

a Total feed intake per cycle.
b Slurry output estimated per cycle (adapted from O’Callaghan et al., 1971).
c Feed intakes and slurry outputs estimated for a typical 145 day cycle for sows, including the 36 day ‘lactation’ phase.
d Annual N output based on 90% occupancy, except sows, where 2.3 litters/year assumed (83 days) and 282 days dry period (for literature data on sows, see Table 3).
estimates of N excretion by nutrient balance (see below). Further validation is possible for growing/fattening pigs from recent studies at ADAS Terrington, on dietary manipulation effects on nitrogen retention (Lee et al., 1995b). Here growing and finishing boars weighing between 30 and 55 kg, and 60 and 90 kg were used in a series of balance experiments in which diets of varying crude protein were formulated on a total amino acid basis. From the information on intakes for the different groups of animals in these replicated experiments, likely slurry outputs were calculated, using the ‘model’ and an estimate of likely slurry N excretion was then made, assuming ‘standard’ slurry N content; these values, however, related poorly with the measured outputs (faeces and urine collected daily and analysed):

\[ \hat{N}_{\text{E pred}} = 0.45 \hat{N}_{\text{E ms}} + 17.3 \quad (r^2 = 0.43), \]

where \( \hat{N}_{\text{E pred}} \) is predicted N excretion in g/day and \( \hat{N}_{\text{E ms}} \) is measured N excretion in g/day.

Other studies at ADAS Terrington (R Kay, personal communication) have confirmed that the relationships established from observations on fattening pigs can also be used to successfully predict the volume of slurry output for weaners:

\[ V_{\text{pred}} = 0.78V_{\text{ms}} + 0.26 \quad (r^2 = 0.90) \]

but, as in the case of the experiments on growing pigs (Lee et al., 1995b), this approach failed to accurately predict slurry N output \( (r^2 = 0.24) \). It appears that the ‘model’, will successfully estimate slurry volume, but such a simple, empirical approach, which makes no attempt to take account of dietary composition, is not capable of adequately accounting for N balance.

3.1.2. Sows

Although the work of O’Callaghan et al. (1971) covered only fattening pigs, the approach has also been applied to lactating and dry sows, using information on feed intakes for sows in commercial practice (Newsham Hybrid Pigs Ltd, 1995) and typical water intakes. Based on a number of sources of data, for both dry and lactating sows, a water to meal ratio of 4:1 has been assumed, which requires the following equation from Table 1 to be used to estimate slurry output:

\[ y = 0.717x - 0.263 \quad (r = 0.980). \]

The limited information available for breeding sows in the literature tends to relate to sows with litters, generally 25 kg LW. Recent literature estimates are summarised in Table 3 and the mean of these estimates for annual N output (28.8 kg/sow/yr), is close to the combined estimate of 29.7 kg/sow/yr (Table 2) for sows and progeny to 25 kg, where appropriate contributions (lactating sow, dry sow, weaner, grower up to 25 kg) have been added together.

3.1.3. Comparison of empirically derived ‘standards’ with nutrient balance estimates

Estimates of daily excretal output, combined with ‘typical’ slurry N content (MAFF, 1994; K Smith, unpublished data), allow estimates of annual N excretion (Table 2). These are summarised as suggested guideline ‘standards’ in Table 4, together with the implications for animal numbers per hectare that equate with the limits on organic manure N application required within Nitrate Vulnerable Zones (MAFF, 1998a).

Calculations, based on the balance between feed N inputs and animal product N outputs (growth of sow, LW gain in progeny), have been made but are not shown here. Comparison of N balance estimates with empirical estimates has been made (Table 7), in the case of the finishing pig place assuming approximately 90% occupancy; N balance calculations were made for sow and progeny to 30 kg LW, assuming a typical 23 progeny/sow/yr. The shortfall in the empirical estimate of N output for finishers of 27% is in line with such comparisons for other stock. Whilst the empirical estimate for sows differs by 38% from the N balance value, the

Table 3

<table>
<thead>
<tr>
<th>Source</th>
<th>Category</th>
<th>Daily output (kg)</th>
<th>Annual output * (t)</th>
<th>N content (kg/t)</th>
<th>Daily N output (g/day)</th>
<th>Annual N output (kg/yr)</th>
<th>DM content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRCC, 1983 (Canada)</td>
<td>+ prog?</td>
<td>11.3</td>
<td>4.12</td>
<td>5.7</td>
<td>64.4</td>
<td>23.5</td>
<td>9</td>
</tr>
<tr>
<td>Manitoba Agriculture, 1994</td>
<td>+ litter (181 kg LW total)</td>
<td>9.0</td>
<td>3.27</td>
<td>5.8</td>
<td>52.3</td>
<td>19.1</td>
<td>–</td>
</tr>
<tr>
<td>SAC, 1992</td>
<td>+ litter (3 weeks)</td>
<td>14.3</td>
<td>5.22</td>
<td>6.0</td>
<td>85.8</td>
<td>31.3</td>
<td>10</td>
</tr>
<tr>
<td>Walther et al., 1994</td>
<td>+ litter 25–30 kg</td>
<td>15.9</td>
<td>5.80</td>
<td>6.0</td>
<td>95.4</td>
<td>34.8</td>
<td>6</td>
</tr>
<tr>
<td>Laursen, 1995 (DK)</td>
<td>+ litter 25 kg</td>
<td>12.2</td>
<td>4.45</td>
<td>7.4</td>
<td>90.6</td>
<td>33.1</td>
<td>8.3</td>
</tr>
<tr>
<td>van Eerdt, 1994</td>
<td>+ litter 25 kg</td>
<td>14.2</td>
<td>5.18</td>
<td>6.0</td>
<td>85.2</td>
<td>31.1</td>
<td>5</td>
</tr>
<tr>
<td>van der Hoek., 1992</td>
<td>+ litter</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>LUFA, 1989 (Germany)</td>
<td>+ litter</td>
<td>13.7</td>
<td>5.00</td>
<td>5.0</td>
<td>68.5</td>
<td>25.0</td>
<td>5</td>
</tr>
<tr>
<td>PARCOM, 1993 Germany</td>
<td>+ litter 25 kg</td>
<td>14</td>
<td>5.11</td>
<td>6.5</td>
<td>90.4</td>
<td>33.0</td>
<td>10</td>
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<tr>
<td>Ziegler and Heduit, 1991</td>
<td>+ litter?</td>
<td>15.8</td>
<td>5.77</td>
<td>5.5</td>
<td>86.9</td>
<td>31.7</td>
<td>10</td>
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<tr>
<td>Mean</td>
<td></td>
<td>13.4</td>
<td>4.9</td>
<td>6.0</td>
<td>79.9</td>
<td>28.8</td>
<td>7.9</td>
</tr>
</tbody>
</table>

* Annual estimates, where calculated from daily figures, assume 100% occupancy.
<table>
<thead>
<tr>
<th>Type of livestock</th>
<th>Age (Range or average)</th>
<th>Body weight (kg)</th>
<th>Production of excreta</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>Daily (kg or l)</td>
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<td>Annual (m^3 or tonnes)</td>
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<td>DM (%)</td>
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<td>N (kg/m^3)</td>
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<td>Annual N excretion (kg)</td>
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<td>Animal numbers per ha to comply with max N loading (kg/ha)</td>
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<tr>
<td>Pigs</td>
<td></td>
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<tr>
<td>Maiden gilts</td>
<td>90–130</td>
<td>7.1</td>
<td>2.60</td>
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<td></td>
<td></td>
<td></td>
<td>100</td>
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<td>16.1</td>
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<td></td>
<td></td>
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<td>19.2</td>
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<tr>
<td>1 sow place, including litters b</td>
<td>130–225</td>
<td>10.9</td>
<td>3.95</td>
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<td>Weaners</td>
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<td>41.0</td>
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<td>Light cutter, meal fed</td>
<td>11–20 weeks</td>
<td>35–85</td>
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<tr>
<td>Bacon, dry meal fed</td>
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<td>35–105</td>
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<td>7.0</td>
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<td>16.2</td>
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<td>23.8</td>
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<tr>
<td>Bacon, liquid fed (@ 4:1)</td>
<td>11–23 weeks</td>
<td>35–105</td>
<td>7.2</td>
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<td></td>
<td></td>
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<td>2.35</td>
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<td>23.8</td>
</tr>
</tbody>
</table>

**Table 4**

Quantities and nitrogen content of livestock excreta

**Pork**

- *Maiden gilts* (90–130 kg, 7.1 kg daily):
  - 2.60 kg annual excreta
  - 100% occupancy
  - DM (%) N (kg/m³) 6 5.0 13.0
  - Animal numbers per ha to comply with max N loading (kg/ha) 13.1, 16.1, 19.2

- *Sows based on 2.3 lactations, covering 23% of yr and dry period 77% of yr. Combined output 19.5 kg N/sow/yr.*

**Weaners**

- 3–7.5 weeks, 7–18 kg:
  - 1.3 kg daily
  - 0.43 kg annual
  - 90% occupancy
  - DM (%) N (kg/m³) 10 7.0 3.0
  - Animal numbers per ha to comply with max N loading (kg/ha) 56.7, 70.0, 83.3

**Growers, dry meal**

- 7.5–11 weeks, 18–35 kg:
  - 2.7 kg daily
  - 0.88 kg annual
  - 90% occupancy
  - DM (%) N (kg/m³) 10 7.0 6.1
  - Animal numbers per ha to comply with max N loading (kg/ha) 27.9, 34.4, 41.0

**Light cutter, meal fed**

- 11–20 weeks, 35–85 kg:
  - 4.1 kg daily
  - 1.35 kg annual
  - 90% occupancy
  - DM (%) N (kg/m³) 10 7.0 9.4
  - Animal numbers per ha to comply with max N loading (kg/ha) 18.1, 22.3, 26.6

**Bacon, dry meal fed**

- 11–23 weeks, 35–105 kg:
  - 4.5 kg daily
  - 1.5 kg annual
  - 90% occupancy
  - DM (%) N (kg/m³) 10 7.0 10.5
  - Animal numbers per ha to comply with max N loading (kg/ha) 16.2, 20.0, 23.8

**Bacon, liquid fed (@ 4:1)**

- 11–23 weeks, 35–105 kg:
  - 7.2 kg daily
  - 2.35 kg annual
  - 90% occupancy
  - DM (%) N (kg/m³) 6 4.5 10.5
  - Animal numbers per ha to comply with max N loading (kg/ha) 16.2, 20.0, 23.8

**Poultry**

- *1000 Laying hens* (2200 kg, 115 kg daily):
  - 41.0 m³ annual excreta
  - 97% occupancy
  - DM (%) N (kg/m³) 30 16 660
  - Animal numbers per ha to comply with max N loading (kg/ha) 260, 320, 380

- *1000 Broiler places* (42 days, 2200 kg, 60 kg daily):
  - 16.5 m³ annual excreta
  - 76% occupancy
  - DM (%) N (kg/m³) 60 30 495
  - Animal numbers per ha to comply with max N loading (kg/ha) 345, 425, 505

- *1000 Broiler breeders* (280 days, 3400 kg, 217 kg daily):
  - 61.0 m³ annual excreta
  - 77% occupancy
  - DM (%) N (kg/m³) 30 16 975
  - Animal numbers per ha to comply with max N loading (kg/ha) 175, 215, 255

- *1000 Replacement pullets* (20 weeks, 1600 kg, 56 kg daily):
  - 7.8 m³ annual excreta
  - 38% occupancy
  - DM (%) N (kg/m³) 30 16 125
  - Animal numbers per ha to comply with max N loading (kg/ha) 1360, 1680, 2000

- *1000 Turkeys (male)* (140 days, 13500 kg, 159 kg daily):
  - 46.4 m³ annual excreta
  - 80% occupancy
  - DM (%) N (kg/m³) 60 30 1390
  - Animal numbers per ha to comply with max N loading (kg/ha) 120, 150, 180

- *1000 Turkeys (female)* (120 days, 6500 kg, 74 kg daily):
  - 21.7 m³ annual excreta
  - 80% occupancy
  - DM (%) N (kg/m³) 60 30 650
  - Animal numbers per ha to comply with max N loading (kg/ha) 260, 325, 385

- *1000 Ducks* (50 days, 3400 kg, 290 kg daily):
  - 90 m³ annual excreta
  - 85% occupancy
  - DM (%) N (kg/m³) 30 10 900
  - Animal numbers per ha to comply with max N loading (kg/ha) 190, 235, 280

---

**Note:**

- a Maiden gilts, assuming all year round accommodation.
- b Sows based on 2.3 lactations, covering 23% of yr and dry period 77% of yr. Combined output 19.5 kg N/sow/yr.
- c Replacement pullets, output per 20 week cycle, assuming manure N content similar to layer manure.
- d Broilers, output per 6.6 crops/yr, 42 day cycle (76% occupancy).
- e Turkeys, assuming 2.1 or 2.4 crops per yr, male and female birds.
- f Estimate based on N balance calculations, adjusted for estimated ammonia loss, in the absence of other measurements on breeders.
Calculations include four separate components (gestating sow, lactating sow, weaner and grower phases), thereby introducing greater possibility for error in the overall figure. The shortfall between the empirical estimates of N output and excretion by nutrient balance calculations are generally within the range of N losses reported from animal excreta by ammonia volatilisation from buildings and storage. In an ammonia emissions inventory for the UK, N losses from pigs, attributed to housing and manure storage were estimated at 17.2 and 4.1 kt, respectively (Pain et al., 1997). This represents ca. 26% and ca. 6% of the estimated total annual N excretion by pigs in buildings, of about 65 kt. These comparisons, therefore, serve to increase confidence that the proposed ‘standards’ for pigs derived in this review (Table 4), are reasonable.

3.2. Poultry

While many of the reservations about typical or general estimates of excretal amounts and quality discussed earlier apply to poultry, the following system-specific caveats are particularly important.

**Broilers**: Waste outputs and N content are likely to be subject to several sources of variability; effects of many of these factors have been described in detail by Tucker and Walker (1992).
- errors in estimate of % occupancy;
- killing age and its effect on nitrogen retention;
- dietary composition;
- food spillage;
- mortality;
- factors affecting litter moisture content;
  - environmental (ventilation, condensation, floor water);
  - nutritional (e.g. salt content, protein quality and quantity, certain ingredients, certain additives such as enzymes);
  - drinker design;
  - litter materials and quantities used;
  - stocking density;
  - management;
  - disease;

**Turkeys**: Factors listed under broilers but an additional factor is breed.

**Layers**: Housing type (deep pit, single storey, stilt house, barn etc.) has a major effect and so has the ventilation system. Within housing type, variability is affected by many of the factors described for broilers. The factors affecting litter quality, are relevant to perchy and barn systems.

Thus, individual flocks may often achieve waste and excretion levels which differ from standard figures. Since some of the empirical estimates for poultry might be perceived as of a rather more speculative nature than for other stock, the detailed calculations for nutrient balance take on extra importance and have been set out in each case. In all the estimates of N excretion for poultry, the assumption has been made that crude protein (CP) contains 16% N, so that N content is given by CP \times 1/6.25 (McDonald et al., 1995), except for egg protein, for which a divisor of 6.68 is more appropriate (Coultate, 1996).

### 3.2.1. Layers

An empirical estimate of 115 g/day excreta at 30% DM, for adult layers has been based on measurements undertaken at ADAS Gleadthorpe from 1987 to 1989 (Alvey, unpublished data) and supported by studies at the University of Bristol, Animal Husbandry Department (Perry, personal communication, 1991). There appeared to be no effect of bird age on feed intake or faecal output, but the latter two parameters were, roughly, linearly related. Higher feeding levels were used in the Bristol University studies but, when plotted against faecal outputs, the combined data followed the same linear trend as the original Gleadthorpe data (Fig. 2).

On the basis of typical feed intake of about 120 g/bird/day (though intakes are often rather less than this in current, efficient systems) for caged birds in intensive production, an output of 34.4 g/day faecal DM, or 115 kg/day fresh excreta per 1000 birds is expected, assuming droppings at 30% DM. Excretal N output can then be estimated by extrapolation, taking account of recent survey data, which suggest an N content of 18.0 kg/t at 30% DM (Nicholson et al., 1996) and other data on manure nutrient content (K Smith, unpublished), with a corresponding value of 15.6 kg/t. Allowing for a short period for building, cleaning and re-stocking, say 97% occupancy, 41 t/yr total output at 16 kg/t N content, therefore, represents an output of 660 kg/yr N/1000 birds (Table 4).

Patterson (1994) reported the results of studies where manure outputs were estimated from eight flocks of commercial Leghorn hens, in deep-pit accommodation. Observations included egg production, body weight, feed consumption and analysis, as well as gross estimate of manure output via records of number and average

![Fig. 2. Effect of feed intake on output of droppings from laying hens (data from ADAS Gleadthorpe and University of Bristol).](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAAQAAAAcCAIAAABQfDQAAAABGdBTUEAALGPC/xgAAAB10lEQVR42mP8/8/wCwA7kSgYv+Yw...
weight of loads, at house emptying. A significant relationship was found between feed intake and manure output, with 0.33 kg manure (fresh weight basis) generated per kg feed intake – representing a manure output of 12.5 t/1000 birds/yr. This estimate, and the total N output estimated at 243 kg/1000 birds/yr, are well below the figures suggested in this study, but the author suggested that the composting process occurring during long term storage could explain the estimated reduction in manure volume of >50% and N losses of about 42% by ammonia volatilisation. These results emphasise that storage conditions can have a major effect on apparent manure N outputs.

It is interesting to note that average N excretion per 1000 birds, from a range of recent literature sources, assuming a notional, annual occupancy of 95%, is 641 kg/yr (with average manure N content at 15 kg/t and output of droppings at 130 kg/10 day), agreeing very closely with the empirical estimates above.

\[ N \text{ balance estimate: Based on the published results of} \]

\[
\begin{align*}
N \text{ Intake} & \quad \text{365 days} \times 120 \text{ g feed/day} \times 0.155 \text{ (protein)} \times 1/6.25 = 1086 \text{ g/bird/yr} \\
N \text{ Retention} & \quad \text{306 eggs} \times 64 \text{ g (egg weight)} \times 0.106 \text{ (protein)} \times 1/6.68 = 311 \text{ g/bird/yr} \\
\text{Excretion by difference} & \quad = 775 \text{ g N/bird/yr} \\
\text{but allowing for only 95% annual production} & \quad = 736 \text{ g N/bird/yr}
\end{align*}
\]

3.2.2. Pullets

Published figures/advisory estimates are few but existing guidelines (Table 5), suggest an output of about 125 kg N per cycle of 20 weeks, which may be a slight overestimate, since pullets now tend to occupy rearing accommodation for less than 20 weeks.

\[ N \text{ balance estimate (to 20 weeks of age, based on} \]
liveweight and feed intake of recent pullets at ADAS Gleadthorpe).

\[ 1.6 \text{ kg liveweight, at 24.5% protein (Leeson and Summers, 1984)} \]
\[ \text{Body N} \quad 1.6 \text{ kg} \times 0.245 \times 1/6.25 = 0.063 \text{ kg N/bird} \]
\[ \text{Feed intake} \quad 7.4 \times 0.165 \times 1/6.25 = 0.195 \text{ kg N/bird} \]
\[ \text{(grower ration average 16.5% protein)} \]
\[ \text{Difference} = 0.132 \text{ kg N/bird} \]
i.e., suggested N excretion, 132 kg N/1000 birds per 20 week cycle.

3.2.3. Broilers

Studies on litter use at ADAS Gleadthorpe (Lynn and Spechter, 1986) have suggested that 100 mm depth of woodshavings is most effective in terms of final litter moisture and bird quality; however, this represents about 2.16 kg litter/bird and is well in excess of commercial practice, where 50 mm of litter (about 1.0 kg shavings or 0.65 kg chopped straw) are more typical. A computer programme ‘BTMANURE’ (Haywood, unpublished, 1991), based on ADAS Gleadthorpe data for liveweights (with default values interpolated by Gompertz function), typical feed digestibilities and feed conversion ratio (FCR – i.e., kg feed intake/kg LW gain), has been successfully used in consultancy work to estimate manure outputs. Using a stocking density of 16 birds/m², feed energy level of 13.0 MJ/kg, litter depth of 50 mm and final litter DM of 60%, model estimates for manure output have been made for a range of cropping cycles.

Measurements from metabolism experiments undertaken at the University of Bristol (Perry, personal communication, 1991) indicated a faecal output, over the 50–54 day period, of 52 g/bird per day for 2.6 kg male birds and 43 g/bird per day for 2.3 kg females. In these experiments, the birds were kept in groups of 15, on wire. For meaningful comparison, an estimate of likely faecal solids output derived from the model is necessary, e.g., for male birds, over 49 day cycle and assuming 50 mm (1.0 kg per bird) litter:

\[ \text{total manure output, 1000 birds (49 days)} = 2220 \text{ kg DM days}, 3.7 \text{ t at 60% DM which includes approx. shavings use} \]
\[ \text{1000 = 800 kg DM kg, at assumed 80% DM faecal DM output therefore 1420 kg, i.e.,} = 29 \text{ g/bird/day over cropping cycle} \]

Table 5

<table>
<thead>
<tr>
<th>Source</th>
<th>Annual output (t)</th>
<th>N content (kg/t)</th>
<th>N output (kg/yr)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manitoba Agriculture (1995)</td>
<td>14.0</td>
<td>–</td>
<td>240</td>
<td>(2 cycles)</td>
</tr>
<tr>
<td>Walther et al. (1994) (Switzerland)</td>
<td>–</td>
<td>–</td>
<td>340</td>
<td>(2.2 cycles)</td>
</tr>
<tr>
<td>Laursen (1995) (Denmark)</td>
<td>7.1</td>
<td>17.3</td>
<td>123</td>
<td>(140 day cycle)</td>
</tr>
<tr>
<td>PARCOM (1993) (Denmark)</td>
<td>–</td>
<td>–</td>
<td>280</td>
<td>(2.2 cycles)</td>
</tr>
</tbody>
</table>
Whilst this output is well below that measured in the Bristol University experiments, model predictions, when assessed over the same age range as the experimental birds, indicate that the predicted faecal output and the experimental observations are in reasonable agreement (Fig. 3). An attempt was also made to check the model predictions against an assessment on a commercial unit (Haywood, 1991 personal communication). The crop consisted of 12,838 birds, as hatched, stocked at 27.9 birds/m² on 50 mm shavings, over a cycle of 43 days (expected end weight 2.15 kg). Manure output was measured at 27.9 tonnes, at 57.8% DM, or 50.5 kg/1000 birds/day and compared well with a predicted 29.2 tonnes, or 52.9 kg/1000 birds/day.

The model does not attempt to describe protein metabolism and N excretion and so, estimates of excretal output must be combined with litter N content (typical or measured), to provide an estimate of manure N excretion. Currently, typical broiler performance is 2.2 kg LW, in 42 days, with FCR of 1.77 (Charles and Tucker, 1997), which from the model would suggest a litter output of 2.5 tonnes/1000 birds/day and compared well with a predicted 29.2 tonnes, or 52.9 kg/1000 birds/day.

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The model does not attempt to describe protein metabolism and N excretion and so, estimates of excretal output must be combined with litter N content (typical or measured), to provide an estimate of manure N excretion. Currently, typical broiler performance is 2.2 kg LW, in 42 days, with FCR of 1.77 (Charles and Tucker, 1997), which from the model would suggest a litter output of 2.5 tonnes/1000 birds/day and compared well with a predicted 29.2 tonnes, or 52.9 kg/1000 birds/day.

Table 6

<table>
<thead>
<tr>
<th>Diet</th>
<th>Feed intake a (kg/day)</th>
<th>Litter output a (kg/day)</th>
<th>Litter N content b (kg/t)</th>
<th>Output (kg/year)</th>
<th>Final bird LW (kg)</th>
<th>N recovery (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>111.4</td>
<td>57.85</td>
<td>20.6</td>
<td>326.8</td>
<td>2.70</td>
<td>86.5</td>
</tr>
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<td>2</td>
<td>112.7</td>
<td>60.42</td>
<td>27.2</td>
<td>451.3</td>
<td>2.78</td>
<td>91.1</td>
</tr>
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<td>3</td>
<td>108.2</td>
<td>51.60</td>
<td>28.5</td>
<td>402.6</td>
<td>2.77</td>
<td>84.7</td>
</tr>
<tr>
<td>4</td>
<td>109.3</td>
<td>52.81</td>
<td>24.0</td>
<td>347.0</td>
<td>2.66</td>
<td>81.0</td>
</tr>
<tr>
<td>Mean</td>
<td>110.4</td>
<td>55.67</td>
<td>25.1</td>
<td>381.5</td>
<td>2.73</td>
<td>85.8</td>
</tr>
</tbody>
</table>

a Feed intakes and litter outputs calculated per 1000 birds.

b Annual litter output, assuming 75% occupancy of bird places.

N output (kg/yr) = 0.13(LW kg/1000 birds) + 242

At the typical 2200 kg liveweight/1000 birds, the above suggests an N output of 528 kg/yr.

Sampling of the litter output from an experimental crop of birds at ADAS Gleadthorpe was undertaken in 1991 (Haywood, personal communication). Ten samples of litter were collected after cropping in accommodation for 600 broilers; litter from quadrats 0.5 × 0.5 m² were weighed and sampled for analysis. Estimated output over the 54 day cropping cycle was 69.4 kg/1000 birds; the analysed litter sample contained 24.3 kg/t N and the calculated litter N output was therefore 462 kg/yr per 1000 birds, assuming 75% occupancy, although the experimental assessments themselves were from a longer cropping cycle than is now common.

In a replicated experiment in 1996/97 at ADAS Gleadthorpe, nutrient and heavy metal balances were studied on groups of 500 broilers reared on 4 different commercial diets, over a 49 day period (Nicholson, 1997). The results summarised in Table 6, cover litter and N outputs only. It is worth noting that the recorded N recovery in these balance studies was 85.8%, increasing confidence in the relevance of the estimates and, suggesting that around 14% N loss, probably by ammonia volatilisation (not measured), is likely to have occurred. From these results, also, the earlier estimate of 610 kg N/yr output per 1000 birds (MAFF, 1994) appears well in excess of likely current industry performance. Since the previous estimates, there have been genetic improvements in growth rate and changes in nutritional practice, which are likely to have affected N excretion and litter quality and the N balance calculation (below) indicates an output of only 350 kg/yr.


**N balance estimate:** Nitrogen balance calculations for an ‘as hatched’ flock to 42 days of age:

Total feed intake

\[ 3.9 \times 0.195 \times 1/6.25 = 0.122 \text{ kg N/bird} \]

Total N retention in carcass (to 2.2 kg liveweight)

\[ 2.2 \times 0.195 \times 1/6.25 = 0.069 \text{ kg N/bird} \]

Liveweight increase

(assuming data for whole bird protein content from Moran, 1995)

\[ 0.053 \text{ kg N/bird} \]

At 6.6 batches/yr (75% occupancy), this gives an estimate of N excretion of 0.35 kg N/bird place/yr (350 kg N/1000 birds/yr). The above calculations have assumed a weighted average protein content, for the range of feeds used. Note, also, that the crude protein content of broiler feeds can vary widely, depending on the use of synthetic essential amino acids.

### 3.2.3. Broiler breeders

In the absence of satisfactory measurements or empirical estimates of manure output from this category, only approximate N balance calculations can be used as a basis for excretion by broiler breeder females.

**N balance calculations:**

**Egg production**

\[ 159 \text{ eggs} \times 64 \text{ g} \times 0.106 = 161 \text{ g N/yr} \]

(protein) \[1/6.68\]

**Feed intake**

\[ 165 \text{ g/day} \times 0.16 = 4.224 \text{ g/day} \]

(protein) \[1/6.25\]

Over 280 day cycle

\[ 1183 \text{ g} \]

\[ = 1022 \text{ g N/cycle} \]

(A 280 day cycle represents 77% annual 1.022 kg occupancy)

\[ N/yr/bird \]

For each female there will normally be 0.1 males, retaining only the N of weight gain. Thus about 0.1 x 0.1 = 0.0102 kg N excretion per yr per female should be added, making a total of about 1.124 kg N excretion per female space per yr. If the cropping cycle is arranged on a tighter schedule than 280 days within the year, then an upward adjustment will be needed to allow for accommodation occupancy. Of course, the suggested standard figure for annual N excretion should be less than that estimated by the N balance approach, in order to be consistent with such estimates for other livestock classes. In this case the mean difference between the two estimates for other classes of poultry (Table 7), excluding broilers (where this difference is negative for reasons discussed above) and ducks (where management was felt to be different), at 13%, means that a standard annual N excretion of about 975 kg/1000 birds is appropriate.

### 3.2.5. Turkeys

The UK industry is now dominated by a few major producers, with year-round production; but a large number of ‘traditional’ producers still target the Christmas market. Collectively these are responsible for, perhaps about 4 million birds per yr, out of a total of 30–35 million (Bray, personal communication). Nationally the flock comprises 50% hens and 50% stags, with females kept for up to 120 days and males for 140 day cropping cycles. Down-time on intensive, specialist units is likely to be very small, and the industry estimate of over 30 million birds production for England and Wales, compared to the November turkey census figure of around 10 million birds, suggests over 3 cropping cycles/yr. Agricultural census data for England and Wales 1992–1994 suggest 3.3 cycles, with around 110 days typical, which may represent an average of 100 days for hens and 120 days for stags. In practice, stags

**Table 7**

Comparison of estimated N excretion in livestock wastes and N excretion by nutrient balance calculation

<table>
<thead>
<tr>
<th>Stock</th>
<th>Liveweight (kg)</th>
<th>Occupancy (% of yr)</th>
<th>N excretion (kg)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Empirical estimate</td>
<td>Nutrient balance</td>
<td>kg</td>
<td>%</td>
</tr>
<tr>
<td>Pigs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sow + litter + weaner + grower</td>
<td>Prog to 30 kg</td>
<td>100</td>
<td>32.8</td>
<td>53.1</td>
</tr>
<tr>
<td>Cutter/baconer</td>
<td>30–105</td>
<td>90</td>
<td>10.3</td>
<td>14.1</td>
</tr>
<tr>
<td>Poultry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Layers</td>
<td>2200</td>
<td>100</td>
<td>660</td>
<td>736</td>
</tr>
<tr>
<td>1000 Pullets</td>
<td>1600</td>
<td>33</td>
<td>125</td>
<td>132</td>
</tr>
<tr>
<td>1000 Broilers</td>
<td>2200</td>
<td>80</td>
<td>495</td>
<td>350</td>
</tr>
<tr>
<td>1000 Broiler breeders *</td>
<td>3000</td>
<td>77</td>
<td>975 *</td>
<td>1124</td>
</tr>
<tr>
<td>1000 Turkey stags</td>
<td>13500</td>
<td>80</td>
<td>1390</td>
<td>1753</td>
</tr>
<tr>
<td>1000 Turkey hens</td>
<td>6500</td>
<td>80</td>
<td>650</td>
<td>876</td>
</tr>
<tr>
<td>1000 Ducks</td>
<td>3400</td>
<td>85</td>
<td>900</td>
<td>1230</td>
</tr>
</tbody>
</table>

* For broiler breeders, estimate of N excretion by interpolation from N balance estimate, assuming a similar % difference between empirical estimate and N balance estimate as for other classes of poultry.
are often kept for periods of up to 150–160 days, where there is a requirement for stripping of meat. Maximising the breast meat is therefore essential and these large birds would tend to increase litter and N excretion.

The computer model BTMANURE (Haywood, ADAS, 1991 unpublished) has been developed to make estimates for manure outputs from turkeys, again using information on liveweights, feed intakes and feed digestibilities from studies at ADAS Gleadthorpe (Lynn and Spechter, 1986). Using typical feeding levels, stocking density (5 birds/m²), FCR 2.6–2.8 and feed energy level of 13.0 MJ/kg and typical litter use of 75 mm shavings (around 5.0 kg/bird place), model estimates for daily litter outputs are as follows:

<table>
<thead>
<tr>
<th>Crop cycle (days)</th>
<th>60% DM litter output (kg/bird/day)</th>
<th>70% DM litter output (kg/bird/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males 140</td>
<td>0.159</td>
<td>0.136</td>
</tr>
<tr>
<td>Females 120</td>
<td>0.074</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Recent poultry manure survey data (Nicholson et al., 1996) suggest little distinction between broiler and turkey litter and when these data are combined with literature and other unpublished nutrient content data (K Smith, unpublished):

\[
\%N = 0.067 \times DM\% - 0.93 \quad (r^2 = 0.67) \tag{7}
\]

there seems little to justify a different figure from the broiler litter N content of 30 kg/t at 60% DM. Thus, from the estimated manure outputs of 159 kg/1000 birds per day (males) and 74 kg/1000 birds per day (females), and an assumed occupancy of 80% (approaching 2.1 cycles for male and 2.4 cycles for female birds) total annual outputs per 1000 birds are estimated at 46.4 t and 21.7 t, containing 1390 kg and 650 kg N for males and females, respectively. Apart from their scarcity, literature data are characterized, mostly, by a lack of background information and their great variability, e.g., Canadian estimates for N output from hens at 614 kg/1000 birds/yr and, for toms, 1040 kg/1000 birds/yr (Manitoba Agriculture, 1995); other estimates include 1185 kg/1000 birds/yr (ASAE, 1993) and, from Switzerland, 1400 kg/1000 birds/yr (Walther et al., 1994).

\[
\begin{align*}
\text{N balance estimates:} \\
\text{*Stags Carcass} & = 0.438 \text{ kg N/bird} \\
& \times 1/6.25 \\
\text{Feed} & = 1.273 \text{ kg N/bird} \\
& \times 1/6.25 \\
\text{Difference (excretion)} & = 0.835 \text{ kg N/bird}
\end{align*}
\]

(Using body composition data from Moran, 1995). On an annual basis, 2.4 cycles/yr suggests 1753 kg N/yr/1000 bird places.

\[
\begin{align*}
\text{Feed} & = 0.209 \text{ kg N/bird} \\
& \times 1/6.25 \\
\text{Difference (excretion)} & = 0.365 \text{ kg N/bird}
\end{align*}
\]

The feed crude protein content is very variable, depending on the age and weight at sale of the turkeys. On an annual basis, 2.4 cycles/yr suggests 876 kg N/yr/1000 bird places.

It is worthy to note that, for both broilers and turkeys, lower levels of N excretion can be achieved by feeding low concentrations of dietary crude protein, supplemented with amino acids.

### 3.2.6. Ducks

Production cycles are normally around 50 days, with a 10 day turnaround period, suggesting occupancy of about 85%. Litter is normally straw, with a high usage in finishing accommodation, with a lot of water spillage. The net result is a litter relatively low in dry matter and nutrients.

Based on relatively few reference and other unpublished data, an empirical estimate for annual N excretion per 1000 ducks can be derived. From a limited database, including manure survey information and other analytical data (K Smith, unpublished) a manure N content of around, 10 kg/t at 30% DM, is suggested:

\[
\%N = 0.025 \times DM\% + 0.28 \quad (r^2 = 0.56). \tag{8}
\]

Data available from the literature (not presented here) suggest a mean excretal N output of about 900 kg N/1000 birds/yr. Thus, assuming 6 crops/yr, each of 52 days, an annual N output of 900 kg, in about 90 t of litter (from the ‘typical’ N content), seems appropriate (Table 4).

\[
\begin{align*}
\text{N retention in birds} & = 0.092 \text{ kg N/bird} \\
& \times 1/6.25 \\
\text{Feed intake} & = 0.297 \text{ kg N/bird} \\
& \times 1/6.25 \\
\text{Difference (excretion)} & = 0.205 \text{ kg N/bird}
\end{align*}
\]

Thus, 205 kg N/1000 birds × 6 crops, suggests 1230 kg N/yr surplus.
3.2.7. Comparison of empirically derived ‘standards’ with nutrient balance estimates

For all the poultry data the most important source of potential error in the N balance calculation is the estimation of carcass crude protein content of the whole bird; we know of no recent measurements. The data of Moran (1995) is information reviewed from earlier publications and in many cases the estimates vary. For example CP content for broilers varied from 16.5% to 22.2%, depending on treatment and reference source.

Comparison of the empirical estimates with the N balance calculations, summarised in Table 7, generally indicates an ‘underestimate’ by the empirical approach of about 20% (range 5–27%), apart from the case of broilers. For ducks, the difference from the empirical estimate of 900 kg N/yr is around 27%, and may reflect errors in estimating carcass protein content, as well as N loss via ammonia volatilisation. The differences are generally within the range of N losses reported from animal excreta by ammonia volatilisation from buildings and storage. In an ammonia emissions inventory for the UK, N losses from poultry attributed to housing and manure storage were estimated at 27.4 and 0.5 kt, respectively (Pain et al., 1997), representing ca. 28% of the estimated total annual N excretion by poultry in buildings, of about 100 kt. These comparisons increase confidence in the use of the estimates suggested as ‘standards’ (Table 4).

4. Conclusions

Feed and water inputs, animal/bird size and building environment all have significant impact on the quality and total output of excreta produced by different categories of pigs and poultry.

Relationships between feed and water intake and excretal outputs in fattening pigs have been adapted, using a modern growth curve and current commercial feeding practice, to allow estimates of excretal outputs for different categories of growing and finishing pigs and, also, breeding sows. These predictions appear to be well supported by the limited data available from published and some unpublished sources where excretal outputs from pigs have been measured alongside information on feed inputs. Since some of the empirical estimates for poultry are fewer in number and might be perceived as of a rather more speculative nature than for other stock, the detailed calculations for nutrient balance take on extra importance. In certain categories of poultry, in particular broilers, new information is available which justifies a reduction in the excretal N output ascribed to the birds compared to previous standards (e.g., MAFF, 1994, 1991); moreover, some changes in husbandry and technology have been outlined, which indicate the potential for further reductions in nitrogen excretion. The revised figures are now incorporated into current guidelines on manure management within NVZs (MAFF, 1998a) and into the revised Code of Good Agricultural Practice for the Protection of Water (MAFF, 1998b).

Whilst empirical estimates of N excretion have generally been slightly lower than estimates by nutrient balance, the differences have been compatible with ammonia volatilisation losses following excretion and during the housing and manure storage period; the guideline standard figures proposed therefore appear to be supported by the independent approach provided by nutrient balance calculations. It will be clear from the many caveats that these figures should be used to provide general guidance only and there will be many cases, at the individual farm/production unit level, where quite different figures for waste output and N excretion will be appropriate.

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