A comparison of N and P inputs to the soil from fertilizers and manures summarized at farm and catchment scale

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SUMMARY
Use of fertilizers and manures during 1994 were studied at the farm and catchment scale in the largely agricultural Ythan catchment, north-east Scotland, using farm level census data supplemented by questionnaire data. Grassland accounted for 40% of the agricultural land, and seven farm types represented 87% of the total land, having an average size of 90 ha. The average livestock density of 1–2 livestock units/ha was high compared to Scotland as a whole (0.5). Rates of inorganic fertilizer applied to individual crops in the area corresponded with the national average and current advisory recommendations. At the catchment scale, most fertilizer N was applied to grassland (47%), whereas spring crops received the greatest proportion of the fertilizer P (35%). The annual manure production equated to an average over the catchment of 63 and 16 kg/ha of N and P, respectively. When calculated for farm types these figures ranged from 27 and 6 kg/ha on ‘cereal’ farms to 384 and 163 kg/ha on ‘pig’ farms. The ratio of applied fertilizer N and P varied from 4:1 for ‘general cropping’ to 10:1 for ‘cattle and sheep (lowground)’ farms. There was no significant compensatory reduction in inorganic fertilizer applications on crops, which also had received manures.

INTRODUCTION
Two nutrients frequently considered with respect to diffuse pollution from agriculture are nitrogen (N) and phosphorus (P) (Puckett 1995). Inefficient use of those nutrients is associated with potential losses, which may be sufficient to induce eutrophication (Isermann 1990), where symptoms usually develop at a scale exceeding that of the individual farm, such as a river catchment (Johnes et al. 1996). Two main sources of N and P inputs to the soil, which show a varying contribution between farm types, are inorganic fertilizer and animal manure (Brouwer et al. 1995).

During recent decades, rates of fertilizer N applied to both tillage and grassland in the UK have increased to meet the greater demand on nutrients resulting from larger crop yields and intensive livestock production systems. By way of contrast, application rates of P have shown an overall decline, which has been especially noticeable for grassland (Chalmers et al. 1990). Current fertilizer recommendations for individual crops and grass provide guidance as to the actual amounts required together with the timing of individual applications. While for N a range of factors are taken into account such as soil texture, soil nutrient status, climatic conditions, yield expectation and previous cropping history (MAFF 1994; SAC 1990a, b), those for P are generally less prescriptive (Edwards et al. 1997).

The presence of livestock on a farm can be associated with recycling of N and P from home produced feed, and N and P inputs through feed imports. When these nutrients are considered from a surface balance perspective, the resulting production of manure can be considered as a direct input of nutrients to the soil (Brouwer et al. 1995). Guidelines are available for including allowances for the use of slurries and manures when applying inorganic fertilizers (SAC 1992).

Any measure to reduce nutrient losses, although possibly aiming at reducing losses in a larger region, will have to be implemented at the farm scale. Therefore, the development of ‘action programmes’ as required for Nitrate Vulnerable Zones (NVZs) by the EC Nitrate Directive (EEC 1991) focuses on
integrated management of fertilizers and manure at the individual farm scale. Computer programs are available that assist in the derivation of field specific recommendations, which are capable of evaluating N use efficiency over entire crop rotations (Smith et al. 1997), predicting the N value of applied manures (ADAS 1997) and nutrient budgeting at the whole farm level (Williamson et al. 1994).

The River Ythan catchment, north-east Scotland, has been the objective of study under the Nitrate Directive on the basis of suggested eutrophication of its estuary. The increased algal growth has been linked to the increasing trend of river nitrate concentrations, associated with agricultural land use in the area. Domburg et al. (1998) compared fertilizer and manurial practices in the area during the period 1960–1990, over which a threefold increase of river nitrate concentrations was recorded (NERPB 1995). The annual use of inorganic N in the catchment showed a threefold increase, which is similar to trends elsewhere in the UK (Chalmers et al. 1990; Davies & Sylvester-Bradley 1995), whereas the use of P declined by more than a quarter. The annual production of N and P in animal manure was estimated to have stayed fairly constant. Aspects of agricultural practices in the Ythan catchment in 1994 were studied in more detail against the background of recommendations and possible measurements to improve N and P efficiency. This paper describes the variability in the use of inorganic N and P and in the production and utilization of animal manure in the area, using information collected at individual farms in combination with best estimates from the literature. The farms within the Ythan catchment have been classified into farm types, which are described in detail, to enable comparison between contrasting management practices. Results are also assessed at the catchment scale.

**MATERIALS AND METHODS**

**Study area**

The Ythan catchment comprises an area of ~ 68000 ha, 90% of which is used for agriculture. There is a mixture of livestock and arable enterprises with approximately 40% of the total agricultural land in 1994 under pasture. Further details related to soils, elevation, hydrology and land use are presented in Domburg et al. (1998).

**Sources of farm level information**

All farm enterprises included in this study completed an IACS (Integrated Administration and Control System) form in 1994 (SOAFD 1994), and represented the main agricultural land users. A total of 718 farm enterprises were selected having an average size of 77 ha, representing 90% of the agricultural land within the catchment.

The Scottish Office Agriculture, Environment and Fisheries Department provided information on cropping areas and livestock numbers for all the farms in 1994 from the agricultural June Census. The confidential nature of this information required that all data was either summarized at the farm type level or used cumulatively to describe relationships at the whole catchment scale. In addition, a Farm Nutrient Questionnaire (FNQ), circulated to all farm enterprises, provided information on actual management practices in relation to fertilizer applications, livestock, and collection and management of manure.

**Farmland types**

Based on a European and national classification of farms, specialist farm types can be distinguished where a crop or livestock enterprise or group of crop or livestock enterprises comprises more than two-thirds of the total farm income (EEC 1985; MAFF et al. 1993). Table 1 summarizes the occurrence of farm types in the Ythan catchment. Minor holdings are associated with a wide range of farming activities and are often not the only source of income for the owner, their average area was < 5 ha and they were excluded from the analyses. The remaining farm types, with an average size of ~ 90 ha, together represented 89% of the agricultural area and 80% of the land in the catchment. As a consequence of the relatively small area of ‘horticulture’ and ‘other’ farms, no special analyses at the farm type scale were made for these farms.

<table>
<thead>
<tr>
<th>Farm type</th>
<th>Number</th>
<th>Average area (ha)</th>
<th>% of agricultural land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals</td>
<td>202</td>
<td>93</td>
<td>31</td>
</tr>
<tr>
<td>General cropping</td>
<td>64</td>
<td>119</td>
<td>12</td>
</tr>
<tr>
<td>Horticulture</td>
<td>2</td>
<td>8</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Pigs and poultry</td>
<td>14</td>
<td>60</td>
<td>1</td>
</tr>
<tr>
<td>Dairy</td>
<td>19</td>
<td>128</td>
<td>4</td>
</tr>
<tr>
<td>Cattle and sheep (LFA*)</td>
<td>40</td>
<td>55</td>
<td>4</td>
</tr>
<tr>
<td>Cattle and sheep (low ground)</td>
<td>72</td>
<td>47</td>
<td>5</td>
</tr>
<tr>
<td>Mixed</td>
<td>190</td>
<td>95</td>
<td>29</td>
</tr>
<tr>
<td>Other</td>
<td>61</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>Minor</td>
<td>54</td>
<td>5</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Total</td>
<td>718</td>
<td>77</td>
<td>90</td>
</tr>
</tbody>
</table>

* LFA, Less Favoured Area.
The FNQ response, which was 45% and related to 50% of the agricultural area, showed a regular distribution over farm types and over the catchment area. It was therefore assumed that the FNQ information was representative for individual farm types and for the whole catchment, and the data were treated as a random sample (Cochran 1977). However, since no FNQ returns were received from ‘specialist poultry’ farms, of which there were six in the catchment, these could not be included.

Characterization of the main farm types was based on the June Census with respect to cropping areas and on the FNQ with respect to livestock numbers because this reflected total numbers for the whole year rather than those just present in June. A relative measure of stocking density (SD) was calculated using livestock units (LU) which are defined in terms of feed requirement, where one livestock unit is equivalent to one dairy cow (MAFF et al. 1996).

Fertilizer use

For the whole catchment and for individual farm types, the fertilizer application rate to a crop was multiplied by the crop area to give the total amount of fertilizer applied. Then, the sum of fertilizer applied multiplied by the crop area to give the total amount of the specific fertilizer type, the fertilizer application rate to a crop was determined. Potential nutrient losses during storage and handling were not considered.

To assess whether the differences in fertilizer use per crop and per farm type could be estimated, assuming zero fertilizer application to land for ‘other’ use, which included farm yards, roads, woodlands, bare fallow and set-aside. Fertilizer use in the catchment was compared with the average practice in Scotland in 1994 (MAFF et al. 1995).

Three types of grassland management were distinguished: hay, silage and grazing. The percentages of mown grass cut for hay and silage were obtained from the FNQ, which also provided information on the importance of grazing prior to first cut silage, second cut silage, and aftermath grazing. It was assumed that all the land used for hay also had aftermath grazing. The total fertilizer application rate to silage was calculated as the sum of applications made to first cut silage plus the relative proportions of applications for grazing prior to silage, second cut silage and aftermath grazing.

Trends in fertilizer applications were compared for three of the main crops: winter wheat, spring barley and grass for grazing. Farms were ranked on the basis of their N and P applications to those crops and the cumulative farm area for each crop was expressed as a percentage of the total area of the particular crop on all farms. The relationship between trends in N and P rates was compared using moving averages (Makridakis et al. 1983).

Estimation of manure production and application

Normative figures for production and composition of manure per livestock category were compiled from a variety of sources (Table 2) for estimating manure N and P production. The number of weeks during which animals were housed/kept outdoors was used to separate manure produced indoors, which therefore required storage and handling, from that deposited directly outdoors at grazing. No correction was made for time spent inside for milking during the grazing period, which may be significant on the ‘dairy’ farms. Manure produced indoors was further subdivided into either farm yard manure (FYM) or slurry. On farms that collected both FYM and slurry, an even distribution was assumed between the two. A minimum limit for numbers of livestock per farm that were to be included in the analysis was set, which for cattle and sheep was five, for pigs two and for poultry 50.

To assess the utilization of manure, only land directly owned by each farm was taken into account, and no net import or export of manure was assumed. The application rate of manure collected indoors over the total farm area, together with that deposited directly outdoors over the area of grassland was also determined. Potential nutrient losses during storage and handling were not considered.

The production and annual return (kg/ha) of manure derived N and P was calculated on an individual farm basis. Results are presented (i) per farm type, (ii) for the catchment and (iii) related to the cumulative farm area, where farms are ranked and results are expressed as a percentage of the agricultural land covered by the farms.

Mean values and standard errors per farm type were calculated using a spreadsheet. Since the number of farms within each farm type was limited (i.e. a finite population) and a relatively large fraction of the farmers returned the questionnaire, a finite population correction was applied to the estimated standard errors of estimated sample means (Cochran 1977).

Compensation for use of manure

Farmers were asked to specify to which crops farm yard manure (FYM) or slurry was applied. If no information on distribution of FYM/slurry was provided an equal distribution over the total area of crops and grass was assumed. For each individual crop the farms were divided into two groups: (1) those with no livestock and those with livestock but no application of FYM/slurry to this crop, (2) those with livestock that did apply collected manure to the crop. For both groups area weighted application rates of inorganic N and P on the main crops and grass were calculated. To assess whether the differences in
Table 2. Production and composition of manures per livestock category (after Domburg et al. 1998: Table 3)

<table>
<thead>
<tr>
<th>Livestock category</th>
<th>Production (tonnes/week)</th>
<th>% DM</th>
<th>Composition (kg/tonne)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Dairy cows</td>
<td>2*</td>
<td>25</td>
<td>6.5 1.5</td>
</tr>
<tr>
<td>10 Young cattle</td>
<td>0.6*</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>10 Fattening cattle</td>
<td>1.3*</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>10 Mature sheep</td>
<td>0.28†</td>
<td>11</td>
<td>6.1 0.9†</td>
</tr>
<tr>
<td>10 Fattening lambs</td>
<td>0.154‡</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>100 Fattening pigs</td>
<td>1.5*</td>
<td>25</td>
<td>7 3.1</td>
</tr>
<tr>
<td>10 Sows + litter to 3 weeks</td>
<td>0.5*</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>1000 Battery hens (fresh)</td>
<td>0.8*</td>
<td>30</td>
<td>17 6.1</td>
</tr>
</tbody>
</table>

* SAC (1992); † The Scottish Office (1992), production corrected to tonnes per week; ‡ Hanson (1990), composition corrected to a DM of 11%; DM, dry matter.

Fig. 1. Box and whisker plots showing the range in the relative proportion of (a) spring crops, (b) winter crops, (c) root crops, (d) grass for mowing, (e) grass for grazing and (f) set aside expressed as a percentage of the total farm areas for each farm type. The middle vertical line of each box represents the median value and 50% of the data points lie within the box. The lines extending to either side (‘whiskers’) indicate the general extent of data. Possible and probable outliers are represented by the asterisks.

RESULTS

Characterization of farms and catchment

Approximately 50% of farms were < 50 ha in area and when considered together these represented 15%
Fig. 2. Box and whisker plots showing the range in numbers of (a) cattle, (b) sheep and (c) pigs for each farm type. Explanation as for Fig. 1.

Fig. 3. Area weighted application rates of inorganic fertilizers to a range of crops per farm type: (a) Fertilizer N, (b) Fertilizer P. WW, winter wheat; WB, winter barley; WOSR, winter oilseed rape; SB, spring barley; SO, spring oats; SOSR, spring oilseed rape; POT, potatoes; TS, turnips/swedes; H, hay; SI, silage; GR, grazing. Farm types: ○, cereals; ●, general cropping; □, pigs; ■, dairy; △, cattle and sheep (LFA); ▲, cattle and sheep (low ground); ◆, mixed.

of the total agricultural land. In contrast, the largest 17% of farms with an individual farm size of > 300 ha, accounted for 50% of the agricultural area. The variation in cropping between individual farms within each farm type is shown in Fig. 1, where cropping areas are expressed as a percentage of the agricultural land. Spring crops, particularly barley, were the main arable component irrespective of farm type (Fig. 1a). While winter crops (wheat, barley and oilseed rape) were present on all farm types, the ‘general cropping’ and ‘cereal farms’ had the greatest proportion of these (Fig. 1b). The distribution of root crops was extremely variable with ‘general cropping’ farms having the greatest area of potatoes which averaged 10.5 ha, whereas on ‘mixed’ farms, fodder turnips/swedes predominated, averaging 3 ha (Fig. 1c). The general importance of grassland and therefore livestock for the majority of farms was clearly evident, even on the more specialized ‘cereal’ farms, where on average ~ 25% was in grass (Fig. 1d, e). During 1994, set-aside averaged at 9% and was notably absent from ‘cattle and sheep’ farms (Fig. 1f).

When considering the whole catchment, grassland accounted for the largest area, and represented 39% of the 55000 ha of agricultural land, showing an even
distribution across farm sizes. Spring crops covered 28% of the area (> 15000 ha), of which more than two-thirds was spring barley, the remainder being spring oilseed rape and a small area of oats. Winter crops (17% of the area) consisted of winter wheat (7%) and equal proportions of barley and oilseed rape. Less than 2000 ha were under root crops, and of the remaining area, approximately 5000 ha (~ 10%) were under a form of set-aside.

The range in numbers of cattle, sheep and pigs for farm types is presented in Fig. 2. The important contribution made by cattle and sheep on most farm types is clearly evident (Fig. 2a, b). Cattle for beef production dominated on ‘mixed’ and some ‘general cropping’ farms. Fattening pigs, while being present on some ‘general cropping’ and ‘mixed’ farms, were essentially restricted to the specialist ‘pig’ farms (Fig. 2c). Livestock were absent from 9% of farms (~ 5% of the agricultural area), and a s.d. of 1.2 LU/ha was calculated over the whole catchment.

**Fertilizer use**

Area weighted N applications to winter crops (194 kg/ha) and grass (143 kg/ha) were large compared to those for spring (90 kg/ha), and root crops (85 kg/ha), whereas P inputs were largest to root crops (70 kg/ha), followed by winter crops (36 kg/ha), spring crops (27 kg/ha) and grass (14 kg/ha). Calculated application rates to individual crops for each farm type are shown in Fig. 3. In general, fertilizer inputs on ‘general cropping’ farms were large, while those on ‘cattle and sheep (LFA)’ farms were small. N inputs to winter cereals were relatively small on the intensive livestock farms, while their inputs to grass were large. For spring and root crops, the amounts of N applied were similar, with larger inputs to potatoes compared to turnips. The range in N applications between farm types was greatest for grassland, and P inputs showed most variation for spring oilseed rape and roots.
At the scale of the whole catchment the ‘cereals’ and ‘mixed’ farm types accounted for the majority (~ 70%) of the fertilizer used. Of the remaining farm types, ‘general cropping’ farms accounted for 14 and 20% of the total fertilizer N and P, respectively, while the other farm types individually accounted for < 10% and < 5% of the fertilizer N and P used.

The amount of inorganic N applied in the catchment during 1994 was estimated at 6390 tonnes, which was equally distributed between grass and arable crops, with winter crops receiving ~ 30% of the total N. The inorganic P used totalled 1178 tonnes, with spring crops accounting for the largest proportion (35%), followed by winter crops (29%) and grass (25%). Although the area under root crops was only 3%, it received ~ 10% of the P inputs.

The range in fertilizer applications to winter wheat was relatively small, whereas N applications to spring barley were more variable. Fertilizer use on grassland varied most between individual farms, ranging in intensity of use from low, given no N or P but relying on clover for N, up to high intensity receiving > 300 kg N/ha. While no relationship between the size of N and P inputs was evident (Fig. 4), moving averages of P application rates calculated for the farms ranked on increasing N use showed a related increase in P use.

The overall differences in application rates were small when comparing between national (MAFF et al. 1995) and those for the Ythan catchment (Fig. 5). The main exceptions being potatoes, where N use was below and P use was above the national average, and grass for grazing and silage where N use was also relatively high.

Estimation of livestock density and manure production

Mean s.e. and therefore manure production varied widely between farm types (Table 3). The smallest s.e.s were associated with ‘cereals’ (0.5 LU/ha) and ‘general cropping’ farms (1.0 LU/ha). ‘Pig’ farms at 10.8 LU/ha were especially intensive within the context of the Ythan, with the highest manure production per hectare (384 and 163 kg/ha of N and P). The range in manure N and P produced on the basis of total farm area was considerable, with greater than one order of magnitude difference between the specialist ‘cereals’ and ‘pig’ farms, and was especially apparent for P. Cattle contributed 60% of the total manure derived N, compared with approximately 20% from both pigs and sheep, and, excluding the ‘specialist poultry’ producers, less than 1% from poultry. The pattern was slightly different for P, with a greater relative contribution from pigs. A further breakdown indicated that nearly three-quarters of the cattle manure was derived from beef cattle. The mean manure rates for the catchment were 63 and 16 kg/ha for N and P.

Manure from housed and grazing livestock

Considerable differences between farm types existed when comparing manure production from housed and grazing livestock (Table 4). While the importance of grazing was obvious for ‘cattle and sheep’ farms, where on average < 30% of total manure produced was from housed livestock, this was in contrast to the ‘pig’ units, where > 80% of manure originated...
Table 3. Mean stocking density (LU/ha), total manure production (tonnes), and mean N and P derived from total manure production on the basis of average farm area (kg/ha) for individual farm types (standard errors in brackets)

<table>
<thead>
<tr>
<th>Farm type</th>
<th>Stocking density (LU/ha)</th>
<th>Manure production (tonnes)</th>
<th>Nutrients from manure (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Cereals</td>
<td>0.5 (0.0)</td>
<td>435 (35)</td>
<td>27 (2)</td>
</tr>
<tr>
<td>General cropping</td>
<td>1.0 (0.1)</td>
<td>1072 (162)</td>
<td>53 (8)</td>
</tr>
<tr>
<td>Pigs</td>
<td>10.8 (3.1)</td>
<td>3610 (593)</td>
<td>384 (103)</td>
</tr>
<tr>
<td>Dairy</td>
<td>1.5 (0.1)</td>
<td>1922 (288)</td>
<td>81 (7)</td>
</tr>
<tr>
<td>Cattle and sheep (LFA)</td>
<td>1.4 (0.2)</td>
<td>421 (78)</td>
<td>70 (6)</td>
</tr>
<tr>
<td>Cattle and sheep (low ground)</td>
<td>1.4 (0.2)</td>
<td>427 (106)</td>
<td>86 (18)</td>
</tr>
<tr>
<td>Mixed</td>
<td>1.3 (0.0)</td>
<td>994 (61)</td>
<td>69 (2)</td>
</tr>
</tbody>
</table>

Table 4. Comparison between farm types of manure from housed livestock (%), proportion of FYM (farm yard manure, as opposed to slurry), and mean N and P from manure collected indoors or deposited directly outdoors at grazing expressed on the basis of total area of agricultural land and area of grassland (kg/ha), respectively (standard errors in brackets)

<table>
<thead>
<tr>
<th>Farm type</th>
<th>% manure indoors</th>
<th>% FYM</th>
<th>Indoor (kg/ha)</th>
<th>Outdoor (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td>Cereals</td>
<td>47</td>
<td>87</td>
<td>13 (1)</td>
<td>3 (0)</td>
</tr>
<tr>
<td>General cropping</td>
<td>60</td>
<td>62</td>
<td>27 (5)</td>
<td>9 (2)</td>
</tr>
<tr>
<td>Pigs</td>
<td>81</td>
<td>45</td>
<td>338 (113)</td>
<td>147 (49)</td>
</tr>
<tr>
<td>Dairy</td>
<td>56</td>
<td>64</td>
<td>46 (4)</td>
<td>11 (1)</td>
</tr>
<tr>
<td>Cattle and sheep (LFA)</td>
<td>26</td>
<td>95</td>
<td>22 (4)</td>
<td>5 (1)</td>
</tr>
<tr>
<td>Cattle and sheep (low ground)</td>
<td>29</td>
<td>68</td>
<td>21 (4)</td>
<td>5 (1)</td>
</tr>
<tr>
<td>Mixed</td>
<td>48</td>
<td>72</td>
<td>35 (2)</td>
<td>10 (1)</td>
</tr>
</tbody>
</table>

The majority of the manure produced indoors was in the form of FYM, although slurry was significant on ‘pig’, ‘general cropping’ and ‘dairy’ enterprises. When considered at the whole catchment scale there was an equal distribution between manure produced indoors (51%) compared to that produced outdoors (49%).

The mean application rates of N and P derived solely from manure collected indoors when expressed over the whole farm, were greatest on intensive livestock units and smallest on ‘cereal’ farms. The average N and P rates applied on all grassland by grazing animals, were greatest for ‘pig’ farms, followed by ‘cattle and sheep (low ground)’ and ‘general cropping’ farms, while ‘dairy’ farms showed values below the catchment average. When calculated over the whole catchment application rates of N and P would be equivalent to 31 and 9 kg/ha for manure produced indoors, with an additional 75 and 16 kg/ha of N and P being deposited at grazing to grassland.

A more realistic estimate of the distribution of indoor collected manure over crops and grass in the catchment was obtained using the British Survey of Fertilizer Practice 1994 (MAFF et al. 1995), which specifies the percentage area of individual crops that received FYM or slurry in Scotland during 1994. This indicated that less than 30% of the agricultural land in the Ythan catchment would be expected to actually receive manure. When considering annual rates of manure collected indoors on the area actually receiving applications, N inputs increased from 31 to 113 kg/ha and P inputs from 9 to 35 kg/ha. Nearly half the manure collected indoors would be expected to be applied to grassland.

Compensation for use of manure

Fertilizer N and P applications to the main crops were further compared between farms that do and those that do not apply manure to a particular crop (Fig. 6). No significant differences in application rates where apparent ($P < 0.05$) for winter wheat, which is close
in cropping and livestock numbers within farm types, the analysis indicated some interesting differences related to various farming practices. It should be noted that while fertilizer application rates were available from individual farms, the nutrient content and application rates of manures was estimated using ‘standard’ production and composition values and is therefore subject to some uncertainty.

Livestock and especially cattle represent a major component of the agricultural economy of the Ythan catchment and north-east Scotland in general. This was reflected in the proportion of agricultural land under grass (~ 40%), and in the high s.d. (1.2 LU/ha) in the Ythan catchment in 1994, compared to the estimated values (for 1990/1991) for Scotland (0.5 LU/ha), the UK (0.9 LU/ha), and 12 countries in the European Union (0.9 LU/ha) (Brouwer et al. 1995). The smaller values, certainly for Scotland and the UK, tended to reflect the ‘diluting’ effect of extensively managed upland areas. Comparison of s.d. between individual farm types indicated that while ‘pig’ farms, at 10-8 LU/ha were especially intensive within the context of the Ythan, these were less than the national (31-1 LU/ha) or European (20-5 LU/ha) average for the ‘pigs and poultry’ farm type. In contrast, on the ‘cattle and sheep’ farm types the average s.d. of 1-4 LU/ha was double the UK average (Brouwer et al. 1995). Even on ‘cereal’ and ‘general cropping’ farms livestock were usually present and averaged 0.5 LU/ha, which would not be typical of these farm types in intensive arable areas such as south-east England. In 1994 the majority of the cattle in the catchment were raised for beef production and accounted for approximately three-quarters of the cattle manure. In this respect it is worth noting that in 1994 the full impact of BSE had not occurred.

Fertilizer N use for the total area of crops and grass in Scotland and in England and Wales during 1994 has been reported averaging 133 and 118 kg/ha, with corresponding figures for P being 16 and 19 kg/ha, respectively (MAFF et al. 1995). When considering differences in the use of agricultural land in Great Britain, grass and spring cereals tend to dominate in Scotland, whereas winter cereals and other tillage including potatoes and sugar beet are more common in England especially in eastern areas. In general, fertilizer requirements for winter crops are large compared with spring crops, and potatoes require especially large P inputs. The overall application rates of fertilizer N and P on the total area of crops and grass in the Ythan catchment in 1994 were 134 and 25 kg/ha, respectively. Application rates to individual crops were similar to the average practice in Scotland (MAFF et al. 1995) and to advisory recommendations from the Scottish Agricultural College.

While N application rates to arable crops were generally the smallest, for 'dairy' farms, the appli-

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**DISCUSSION AND CONCLUSIONS**

The farms included in this study were not selected using a representative sampling design, such as generally used for national surveys of fertilizer practice (e.g. MAFF et al. 1995), but since the survey was policy related, all farmers in the study area were given the opportunity to participate. However, analysis of the distribution of the response from the FNQ (45%) showed a regular distribution over the catchment and over individual farm types, which suggested that the data were representative. Despite the large variability to the 1:1 line, or potatoes and turnips, which are furthest away from the 1:1 line.
cations to silage and grazing and the overall fertilizer inputs were among the highest for this farm type. When considering individual crops, N inputs to grass for grazing were shown to be particularly variable between individual farms, with N applications ranging from 0 to 300 kg/ha, associated with a range in intensity of use (Younie et al. 1996), while ~20% of the grazing area received no N fertilizer. The continued large use of P on root crops was clearly demonstrated.

The EC Nitrate Directive concentrates on limits for manure N applied over the farm area, 170–210 kg/ha/yr (EEC 1991). This legislation is estimated to affect only 2 to 3% of the agricultural land in this catchment, and is therefore expected to have little or no immediate impact on the N loss. The annual manure production rate at the catchment scale was estimated to contain 63 and 16 kg/ha of N and P, respectively. In general, the manure N and P produced per area were greater on the livestock farms compared to the arable farms. When considering individual farm types, only the ‘pig’ farms exceeded the proposed limit, producing 384 kg N/ha. These farms also collected the largest proportion (>80%) of their manure indoors. Nearly half the total N and 40% of the total P from animal manure in the area were estimated to be deposited at grazing, being equivalent to returns on grass of 75 and 16 kg/ha for N and P respectively. In the Ythan catchment, the limit of 170 kg N/ha on the grassland is exceeded on grass belonging to 6% of the farms, when considering excreta from grazing animals only. On an individual field basis, it is likely that there are more farms with fields used for intensive grazing, on which the EC limit is exceeded from grazing only. A field based limit for manure N of 250 kg N/ha (excluding grazing) has been proposed in the action programme measures to apply in Nitrate Vulnerable Zones in England and Wales (DETR et al. 1997). In addition to excreta left by grazing animals, between 30 and 40% of the managed grassland in Scotland also receives FYM/slurry (MAFF et al. 1995), resulting in an estimated manure N application of 188 kg/ha, the corresponding value for P being 51 kg/ha.

Smith et al. (1995) gave average annual application rates of P from FYM/slurries from indoor sources on tillage land and grassland in the UK of 14 and 8 kg/ha, respectively, when averaged over all the land. The estimated value over all agricultural land in the Ythan catchment was very similar (9 kg P/ha). When considering the areas actually receiving manure, the estimated P input from handled manure in the UK equals 80 kg/ha on tillage land and 16 kg/ha on grassland (Smith et al. 1998), based on applications on 18 and 48% of the areas of tillage land and grassland. The area of tillage land receiving FYM in Scotland ranges from 15% (winter wheat) to ~50% (root crops), whereas on grassland application rates range from 0% (rough grazing) to ~40% (MAFF et al. 1995). For the Ythan catchment this means application of handled manure on 30% of the agricultural area containing on average 35 kg P/ha (and 113 kg N/ha), with greater amounts being applied to tillage land and slightly smaller amounts to grassland compared with the UK figures.

Most of the indoor collected manure in the area appeared to be stored in the form of FYM (68%). ‘Pig’ farms produced the greatest amount of slurry (55%), which was comparable to the 50% estimated for the UK by Archer (1988). However, the estimate for cattle slurry in the UK, 70% (Archer 1988), was much greater than the estimates for the Ythan catchment: 36% at ‘dairy’ farms and 20% from all cattle at the catchment scale. Although slurries are considered to be associated with greater risks of direct pollution incidences during storage and application (SOAEFD 1997), the storage of FYM in middens in fields, i.e. outside, which is common practice in the Ythan catchment, forms a potential pollution risk from direct runoff.

When considering fertilization of individual crops, no compensation for the nutrient value of FYM and/or slurry was apparent in the use of inorganic fertilizers, indicating an opportunity to improve nutrient efficiency. Similar observations have been made in England and Wales (Chalmers et al. 1992). However, analysis of the data for farm types suggested that compensation was made at ‘dairy’ farms showing smallest N application rates to winter crops.

The importance of integrating the management of N and P in fertilizers and manures at the farm scale is emphasized by the N:P ratio in manure differing from the average crop requirements. Over the whole catchment the N:P ratio to individual crops varied from approximately 1:1 for the root crops, up to approximately 12:1 for grassland. The differences in cropping and use of inorganic N and P between farm types resulted in a range in N:P fertilizer inputs from 4:1 on ‘general cropping’ farms to 10:1 on ‘cattle and sheep (low ground)’ farms. This range was large compared with the N:P ratios in manures produced at the different farm types, between 2:1 and 5:1. Therefore, appropriate compensation for N from manures in the inorganic fertilizer use, may well lead to soil P enrichment (Smith & Chambers 1995). In addition, the availability of manure is unlikely to correspond with the most appropriate timing for application (most manure is collected in the period from November until April) (SOAEFD 1997). Nevertheless, even small reductions in inorganic fertilizers could reduce fertilizer costs and potential environmental pollution, without necessarily leading to a decrease in yield (Smith & Chambers 1993). It should, however, be noted that there are additional factors, such as crop rotation and management, which affect the utilization of fertilizer and manure applications (Sieling et al. 1997). In addition, feed imports
associated with livestock keeping and outputs of nutrients in crop and animal products should be considered when assessing overall nutrient efficiency.

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