The fertilizer value of pig slurry. I. Values depending on the type of operation

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Received 23 January 2004; received in revised form 23 September 2004; accepted 12 October 2004
Available online 2 December 2004

Abstract

151 samples of pig slurries were taken from 83 operations in the Castile-Leon region of Spain. Analysis of them enabled comparison of slurries coming from pig farming operations located in different Spanish and European regions. These operations were classified into three groups, namely maternity (64 samples), closed cycle (35 samples) and fattening (52 samples). For each sample 27 parameters were analysed. Data obtained from each kind of operation were compared. Finally, the fertilizer value of slurries was determined with regard to the relationship between their major elements, N/P₂O₅/K₂O (1/0.6/0.4).

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Keywords: Pig slurry; Fertilizer; Liquid manure; Fertilizing value; Soil amendment

1. Introduction

Using pig slurry as fertilizer in agriculture is the most correct and natural way of decomposing it and also saves a great deal of chemical fertilizers which, apart from their high cost, are already contributing to pollution in some areas (Navarotto, 1982; Ferrer et al., 1983; Jacobs, 1989; Torres, 1993). Considering both its fertilizer value and the increasing cost of chemical fertilizers, the economic value of slurry is beyond doubt (Osborne, 1982; Ferrer et al., 1983).

The essential mineral elements for plant life are found in livestock excreta, which contain nitrogen (N), phosphorus (P) and potassium (K) as well as variable quantities of calcium (Ca), magnesium (Mg), sulphur (S) and trace elements (Castillón, 1993).

The measurement and assessment of the fertilizer value of solid manure and slurries aims to provide farmers with a measure of the real value of these products, thus enabling them to decide the amount of manure to spread based on estimated crop needs and on the levels of these elements in the soil (Bertrand, 1993).

Many authors offer slurry composition values that vary according to the animals’ physiological state and to the operational management conditions (Germon et al., 1979; ITCF, 1982; Ferrer et al., 1983; Torres, 1993). For this reason, the present study examines slurry composition in a specific area, namely the Castile-Leon region of Spain. The operations were grouped according to the animals’ physiological state, as done by previous investigators (Ferrer et al., 1983).

In general, slurry from fattening operations is richer in both mineral and organic dry matter, as well as in nutrient elements (N, P, K, Ca, Mg) and metals such as copper (Cu) and zinc (Zn) (Germon et al., 1979; Ferrer et al., 1983, 2000; Torres, 1993; Calvo et al., 2000).

The purpose of this work was to study the composition of slurry to be used as fertilizer in agriculture.

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2. Methodology

A total of 151 samples of pig slurries from 83 operations in the Castile-Leon region were analysed. The samples were classified into three groups depending on their origin, as indicated by Ferrer et al. (1983). Maternity (64 samples) includes pregnant sows, lactating sows and piglets up to 14–16 kg live weight. Closed cycle (35 samples) comprises maternity and fattening in a single production unit and all the slurries stored in the same pit. Fattening (52 samples) includes pigs from 14–16 kg up to slaughter weight.

The sampling was carried out with a special catheter made to the design by Leiros et al. (1983) in conformity with FAO recommendations (Vermes, 1980). This catheter had a collection skip with a capacity of one litre. Slurry samples were collected with the catheter at different depths in the operation pits. The slurry was first stirred in the pit when the operation possessed the necessary equipment. Each sample was placed in a sealed polyethylene container kept at low temperature (5°C) in a portable refrigerator and moved to the laboratory within 24 h.

In the laboratory the sample underwent careful homogenization using stirring equipment for 10 min. After that, the immediate measurements (pH, electrical conductivity, temperature and density) were taken. Then subsamples were collected for drying and for the analyses that had to be done on fresh sample. The remaining sample was stored in a freezer.

For each sample, 27 composition parameters were analysed according to the methods proposed by the FAO (Vermes, 1980). Density was measured on fresh samples with a densimeter (manufactured by Proton) that had an adequate scale (1000–1100 ± 1). Electrical conductivity was measured on fresh samples with a conductivity meter (Crison 525) with adjustments for temperature. pH was measured directly with a pH meter (MicropH 2001) on fresh material or else in a mixture with a soil–water ratio of 1:2. To determine dry matter, 100 g of dry material were placed in a capsule that allowed a maximum depth of 1 cm of slurry, then dried in a heater at 105°C to constant weight for at least 24 h. Ash content—volatile organic matter was determined using dry material (2 g), which was calcined in a muffle furnace at 450°C for 8 h. Total N was analysed with fresh samples, the quantities of sample and reagents being adapted to the use of a Tecator digestion and distillation unit (Kjeltec System 1026). Ammoniacal N was determined by direct distillation from fresh samples with MgO, distillate collection over boric acid and titration with 0.1 N HCl. Ammoniacal and nitric N was determined by processing the homogeneous fresh sample with Zn, FeSO₄ and H₂O₂. It was distilled in a strong base medium in a Tecator distillation unit; the distillate was collected in 0.5 N H₂SO₄, and subsequently titrated with 0.1 N NaOH. Chlorides were determined in fresh samples by titration with silver nitrate. Ash extraction to determine P and metals was performed with 1 M HCl, heated for 30 min and diluted with distilled water. To determine total P, the coloured phosphomolybdate complex was developed, and the absorbance of this complex at 430 nm was measured in a Hitachi U-2001 spectrophotometer. Inorganic P was determined by mixing the fresh sample with 0.5 M acetic acid in a 1:40 ratio, then it was stirred for 1 h and filtered. The P content in the extract was determined spectrophotometrically as for total P. K, Na, Ca, Mg, Cu, Zn, Fe, Mn, Al, Mo and Pb were measured by atomic adsorption spectrophotometry (Perkin Elmer, Analyst 100) at the corresponding wavelengths, except for Na and K (emission).

3. Results and discussion

3.1. Physicochemical composition of slurry

3.1.1. Total samples

Table 1 shows the data for slurry composition determined with wet material for all the samples, as well as for the three types of production unit, depending on the animals’ different physiological states. The results obtained show the following.

According to Leiros et al. (1983), the density and contents in mineral and organic dry matter are very variable, due to the amount of water used to clean the stable and the kind of pit used to collect the slurries. In open pits, the slurry density will be affected by precipitation during storage; in closed pits, dilution caused by stable cleaning will be the most important factor causing changes of density.

Most of the slurries analysed had a pH value above neutral. Leiros et al. (1983) attribute to slurry some properties that correct soil acidity, whereas other authors recommend the addition of lime to the slurry so as to compensate for its acid-producing effect. The latter procedure is mentioned in the brochure published by the French Ministère de l’Environnement (1984). Only 12 samples of the 151 analysed in the present study had a pH value under 7, and only two of them had a pH value under 6.

Approximately 75% of the N in the slurry was in inorganic form, mainly as ammoniacal N, which represented 57% of the total N content, a value which is similar to the 60% found by Germon et al. (1979) and to the 60–70% mentioned by Bertrand (1993). The rest of the N, about 25%, was in organic form.

Mean values found for C/N ratios were 3.57 with reference to total N, and 24.90 with reference to organic N. Since the inorganic fraction is in the slurry liquid phase and the organic fraction is in the solid phase, some
### Table 1
Average slurry composition for all the samples and types of operation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>All samples (n = 151)</th>
<th>Maternity (n = 64)</th>
<th>Closed cycle (n = 35)</th>
<th>Fattening (n = 52)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Minimum</td>
<td>Maximum</td>
<td>CV</td>
</tr>
<tr>
<td>Conductivity (Sm$^{-1}$)</td>
<td>1.559</td>
<td>0.201</td>
<td>7.518</td>
<td>60.58</td>
</tr>
<tr>
<td>Density (g cm$^{-3}$)</td>
<td>1.015</td>
<td>1.000</td>
<td>1.094</td>
<td>1.30</td>
</tr>
<tr>
<td>pH (1:2)</td>
<td>7.59</td>
<td>5.85</td>
<td>8.65</td>
<td>5.77</td>
</tr>
<tr>
<td>Ash (g kg$^{-1}$)</td>
<td>9.04</td>
<td>1.10</td>
<td>45.73</td>
<td>90.30</td>
</tr>
<tr>
<td>Dry matter (g kg$^{-1}$)</td>
<td>32.41</td>
<td>2.29</td>
<td>199.5</td>
<td>115.02</td>
</tr>
<tr>
<td>Organic matter (g kg$^{-1}$)</td>
<td>23.31</td>
<td>1.12</td>
<td>160.7</td>
<td>127.22</td>
</tr>
<tr>
<td>Chlorides (g kg$^{-1}$)</td>
<td>0.912</td>
<td>0.144</td>
<td>5.476</td>
<td>59.38</td>
</tr>
<tr>
<td>NH$_4$-N (g kg$^{-1}$)</td>
<td>2.61</td>
<td>0.41</td>
<td>10.78</td>
<td>58.33</td>
</tr>
<tr>
<td>Org-N (g kg$^{-1}$)</td>
<td>0.75</td>
<td>0.05</td>
<td>6.82</td>
<td>98.11</td>
</tr>
<tr>
<td>Total-N (g kg$^{-1}$)</td>
<td>0.820</td>
<td>0.043</td>
<td>3.860</td>
<td>100.47</td>
</tr>
<tr>
<td>C/NTot</td>
<td>3.57</td>
<td>0.41</td>
<td>25.22</td>
<td>101.53</td>
</tr>
<tr>
<td>C/NOrg</td>
<td>24.90</td>
<td>1.01</td>
<td>215.76</td>
<td>222.01</td>
</tr>
<tr>
<td>K (g kg$^{-1}$)</td>
<td>1.088</td>
<td>0.088</td>
<td>5.247</td>
<td>64.41</td>
</tr>
<tr>
<td>Mg (g kg$^{-1}$)</td>
<td>0.222</td>
<td>0.004</td>
<td>1.704</td>
<td>118.28</td>
</tr>
<tr>
<td>Ca (g kg$^{-1}$)</td>
<td>1.103</td>
<td>0.039</td>
<td>7.576</td>
<td>117.34</td>
</tr>
<tr>
<td>Na (g kg$^{-1}$)</td>
<td>0.235</td>
<td>0.017</td>
<td>1.482</td>
<td>84.56</td>
</tr>
<tr>
<td>Zn (mg kg$^{-1}$)</td>
<td>24.7</td>
<td>0.31</td>
<td>261</td>
<td>143.31</td>
</tr>
<tr>
<td>Cu (mg kg$^{-1}$)</td>
<td>13.3</td>
<td>0.07</td>
<td>125</td>
<td>150.56</td>
</tr>
<tr>
<td>Pb (mg kg$^{-1}$)</td>
<td>0.29</td>
<td>3.255</td>
<td>143.31</td>
<td>1.97</td>
</tr>
<tr>
<td>Mn (mg kg$^{-1}$)</td>
<td>12.3</td>
<td>0.24</td>
<td>95.3</td>
<td>141.12</td>
</tr>
<tr>
<td>Fe (mg kg$^{-1}$)</td>
<td>73.0</td>
<td>1.51</td>
<td>809.4</td>
<td>157.66</td>
</tr>
</tbody>
</table>

CV: coefficient of variation.
authors, for example Leirós et al. (1983), point out the need to keep both slurry phases together in the soil in order to ensure better mineralization conditions. Besides, the C/N ratio has an influence on N availability. When the ratio is high, soil microorganisms need additional N to decompose C, and the N becomes fixed in organic form. On the contrary, a low C/N ratio indicates a high content of ammoniacal N; as it is then the major component, it can be considered a mineral fertilizer (Thibaudeau, 1997). Moreover, a very low C/N ratio in slurry involves quick mineralization of the soil organic matter, and that is why adding slurry to the soil can cause a loss of organic matter. Consequently, according to Flowers and Arnold (1983) and Skjemstad et al. (1987), the slurry C/N ratio cannot be taken as a mineralization index. There is a need for additional studies of slurry decomposition in the soil and of its effect on fixing and mineralizing N.

The average concentration of total P in wet material was 0.820 g kg$^{-1}$, with extreme values ranging between 0.043 and 3.860 g kg$^{-1}$. Duthion et al. (1979) found that most of the P (about 80% of the total) was in the slurry solid fraction in inorganic form, which plants can assimilate directly; the remaining 20% was in organic form.

The amount of Ca in the slurry was 1.103 g kg$^{-1}$ and the amount of Mg was 0.222 g kg$^{-1}$, which produces a Ca:Mg ratio of 5, roughly what the soil requires. Both elements, as well as P, were mainly found in the solid fraction (Duthion et al., 1979).

The K content was similar to the chloride content, and considerably higher than the Na content. Unlike the other elements, these were mainly found in the liquid phase of the slurry, due to their high solubility (Duthion et al., 1979).

As for the residue of metals analysed, they were within the values indicated by Nicholson et al. (1999) and Calvo et al. (2000). We would emphasise that the slurry was rich in Fe and Al, and to a smaller extent in Zn, followed by Cu and Mn. Pb and Mo only appeared in very low quantities, and were often not detectable at the measurement level used. These metals were mainly found in the solid fraction (Duthion et al., 1979).

### 3.1.2. Values according to type of operation

From Table 1 it is clear that values from closed cycle operations were intermediate between those of fattening and maternity for most variables, since closed cycle farms are a mixture of the other two (Ferrer et al., 1983).

Density and pH present similar values in the total samples from all three kinds of operation, and there are no significant differences between the operations. Nevertheless, conductivity was much higher in fattening operations (1.857 S m$^{-1}$) than in maternity ones (1.441 S m$^{-1}$) and closed cycle ones (1.332 S m$^{-1}$).

The slurry from maternity operations was less rich in dry matter (21.36 g kg$^{-1}$) than slurry from fattening (42.53 g kg$^{-1}$) and closed cycle operations (36.13 g kg$^{-1}$). According to Coppenet (1974), Germon et al. (1979) and Ferrer et al. (1983), it is because animals in this physiological state excrete mostly (80–90%) in the form of liquid faeces with a low dry matter content, and since slurry dry matter is mainly mineral matter, the values of these two variables follow the same trend.

The total N content in wet matter was higher in all fattening operations (4.08 g kg$^{-1}$) than in maternity (2.61 g kg$^{-1}$) and closed cycle operations (3.07 g kg$^{-1}$). This agrees with the findings of Germon et al. (1979).

As Leirós et al. (1983) stated, the organic N fraction is found mainly in the slurry’s solid phase. For this reason, it is higher in slurries with a higher dry matter content, i.e. it is higher in fattening slurries than in closed cycle ones, and higher in closed cycle ones than in maternity ones.

N excreted in ureic form (urine) decomposes quickly into ammoniacal N inside the pit, but organic N (faecal) decomposes slowly. Thus, the ammoniacal N content in the pit will increase within certain limits while the slurry is there, although there will be small losses due to volatilisation, whereas organic N will slowly decrease (Ferrer et al., 1983). When it is used as fertilizer, this has an effect on the slurry’s composition related to its length of stay in the pit.

The peak concentration of P in fresh matter appeared in fattening operations (0.991 g kg$^{-1}$), and the minimum in maternity operations (0.690 g kg$^{-1}$). That of the closed cycle had an intermediate value (0.773 g kg$^{-1}$).

Table 2 shows the percentages of inorganic (ammoniacal + nitric) and organic ammoniacal N in wet material in relation to total N, and the percentages of inorganic and organic P in relation to total P, depending on the kind of operation.

About 80% of slurry N is in inorganic form, mainly as ammoniacal N (over 50% in the three kinds of operation and in the sample total). This N comes mainly from urea decomposition, as Duthion et al. (1979) have pointed out.

The differences found in the percentages of ammoniacal N in relation to total N between the three operational systems are closely related to the animals' physiological state and feeding. Adult pigs have a higher catabolism than growing pigs, so the proportion of ureic N is higher.

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH$_4$-N</td>
<td>Inorg-N</td>
</tr>
<tr>
<td>Total samples</td>
<td>57.76</td>
</tr>
<tr>
<td>Maternity</td>
<td>57.47</td>
</tr>
<tr>
<td>Closed cycle</td>
<td>55.05</td>
</tr>
<tr>
<td>Fattening</td>
<td>59.56</td>
</tr>
</tbody>
</table>
According to Gerritsen (1977), 90% of P is excreted in the faeces in different ways: about 75–80% in inorganic form, and about 12–18% in organic form, both of them in the solid fraction. The rest is dissolved mainly in inorganic form. These proportions agree substantially with the percentages of inorganic and organic P found in the present study.

According to Ferrer et al. (1983), the average P content in fresh matter is about 32% of that of total N, and this percentage is smaller in the case of maternity (24%) and bigger in the case of fattening (38%). These results do not agree with those of the present study. Similar percentages can be observed in the sample total and in the three kinds of operation, although they are slightly higher in maternity operations (26.43%), as shown in Table 3, which shows total N and P contents expressed in g kg⁻¹ in fresh matter, together with the percentage of the one in relation to the other, for the sample total and the three kinds of operation.

Ca and Mg contents are lower in maternity and higher in fattening. According to Ferrer et al. (1983), they are smaller as the dry matter content of the slurry decreases.

As for the residue of metals, Cu acted differently. Its proportion in fattening slurry was much higher than in maternity. Cu acts as a growth factor; hence it is regularly added to fattening diets, and it is almost completely eliminated in the faeces.

Regarding Zn, there were differences between different types of operation but they were not so remarkable, due to it being less used in feed in spite of its well-known effects on fertility.

The slurry was quite rich in Fe compared to other microelements. Mn, on the other hand, only appeared in small quantities.

The Pb and Mo contents found were minimal; however, there were appreciable quantities of Al.

### 3.2. The fertilizing value of slurry

Adding slurry to farming soils means enrichment with considerable quantities of fertilizing substances that have to be taken account of when drawing up a fertilization plan. Hence, it seems appropriate to study the ratio that exists between major nutrient contents as measured in fresh material if one intends to apply the slurry just as it is, or in dry matter if one intends to dry the slurry partially or completely before using it.

Table 4 shows these contents for the sample total and for the three types of operation studied.

The ratio of major nutrients N:P₂O₅:K₂O remain constant in the sample total and in the three types of operation studied when values refer to wet slurry; however, for dry slurry there are variations.

The concentration of major fertilizer elements found is within the limits established in the literature, bearing in mind that the more the slurry is diluted, the less is the content of fertilizer elements. In the slurries analysed in the present study, the dry matter contents were virtually half of those reported by Germon et al. (1979) and Lecomte (1979), and thus the concentration of fertilizer elements is bound to be much smaller.

When the dry matter content in slurries from various European countries, as reported by investigators like Scotford et al. (1999), is close to that found in the present study, the concentrations of nutrient elements and the balance among the three major ones are completely similar.

The fertilizer value (or working coefficient) of slurry expresses the comparative efficiency of a fertilizer element added in this form and a reference mineral fertilizer (usually ammonium nitrate, 45% superphosphate and potassium chloride).

Thibaudeau (1997) estimates an average P working coefficient of 0.80. However, other authors such as Irañeta et al. (1999) have proved in long-term agronomic experiments that all the P can be compared to that of a mineral fertilizer, since the organic part too is mineralized, though slowly, and can become available

### Table 3
Proportions of total N and total P (g kg⁻¹ in fresh matter)

<table>
<thead>
<tr>
<th>Type of farm</th>
<th>Total-N</th>
<th>Total-P</th>
<th>% (P/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total samples</td>
<td>3.22</td>
<td>0.820</td>
<td>25.47</td>
</tr>
<tr>
<td>Maternity</td>
<td>2.61</td>
<td>0.690</td>
<td>26.43</td>
</tr>
<tr>
<td>Closed cycle</td>
<td>3.07</td>
<td>0.773</td>
<td>25.18</td>
</tr>
<tr>
<td>Fattening</td>
<td>4.08</td>
<td>0.991</td>
<td>24.29</td>
</tr>
</tbody>
</table>

### Table 4
Major nutrient contents in the slurries (g kg⁻¹ in fresh matter)

<table>
<thead>
<tr>
<th>Dry matter</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
<th>MgO</th>
<th>CaO</th>
<th>Balance N/P₂O₅/K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole samples</td>
<td>32.41</td>
<td>3.22</td>
<td>1.88</td>
<td>1.21</td>
<td>0.37</td>
<td>1.54</td>
</tr>
<tr>
<td>Maternity</td>
<td>21.36</td>
<td>2.61</td>
<td>1.58</td>
<td>1.03</td>
<td>0.29</td>
<td>1.12</td>
</tr>
<tr>
<td>Closed cycle</td>
<td>36.13</td>
<td>3.07</td>
<td>1.77</td>
<td>0.89</td>
<td>0.38</td>
<td>1.69</td>
</tr>
<tr>
<td>Fattening</td>
<td>42.53</td>
<td>4.08</td>
<td>2.27</td>
<td>1.64</td>
<td>0.46</td>
<td>1.97</td>
</tr>
</tbody>
</table>
to crops. Thus, if P fertilizing is considered in the long
term, the P working coefficient may be equal to 1.

There is high availability of K for crops, since more
than 80% of it occurs in the animal urine in the form
of a water-soluble mineral salt. Its fertilizer value or
working coefficient is 1 (Thibaudeau, 1997; Irañeta
et al., 1999).

N is the fertilizer element which has the most direct
impact on crops, and it is an indicator of the yield of
normal fertility soils. Both lack of it and an excess of
it can cause yield or quality losses, and even damage
the crops. Excessive applications can cause environmen-
tal pollution, so in slurry management it is essential
to adjust the dose to each crop. Knowing N dynamics
enables one to estimate its efficiency. However, the
influence of slurry characteristics and conditions of
use (crop, season, method of application, etc.) make it
necessary to conduct a good field study in order to assess
real efficiency ratios.

Once added to the soil, ammoniacal N in slurry
changes quickly into nitric N, and it may leach if the
plants do not assimilate it. The non-leached part of
nitric N is entirely usable by crops. If the application is
done in a season when it will soon be absorbed by the
crop, losses will be almost negligible. However, applica-
tion in autumn on bare soil and with high precipitation
can cause high N losses.

One part of the organic N in slurry will be trans-
formed into mineral N during the first year, or else dur-
ing the second year if the application is carried out in
autumn. The process is more intense during spring and
autumn, as it is highly affected by temperature and soil
moisture. The crop will exploit this N almost entirely
during the year the slurry is spread.

The rest of the organic N slurry is stored by soil hu-
mus. Its mineralization in the following years will release
a part of the N it contains.

4. Conclusions

There was a great variability in slurry composition
for all the parameters analysed. Both N and P were
mostly found in inorganic form (N 75%, P 80%). Slurry
was rich in Fe and Al, with smaller quantities of Zn, fol-
dowed by Cu and Mn. Pb and Mo only appeared in
small quantities. For most of the parameters analysed,
values concerning closed cycle operations were inter-
mediate between those of fattening and maternity. The
highest values related to slurries from fattening opera-
tions. Density and pH presented similar values in the
three types of operation. Slurries from maternity opera-
tions had lower dry matter content. The ratio among
major nutrients N:P₂O₅:K₂O remained constant in the
sample total and in the three types of operation studied
(1:0.6:0.4).

Acknowledgement

The financing of this study by the Government of
Castilla y Leon is greatly appreciated.

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