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Research Paper

Proportion, composition and potential N mineralisation of particle size fractions obtained by mechanical separation of animal slurry

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Mechanical slurry separation is a useful technology for slurry management on farms. The characteristics of the fractions obtained depend on the separation efficiency and on the characteristics of the original slurry. In the present work, three types of slurry – pig, cow and duck – were separated into 4 particle size fractions. The proportion, composition in terms of carbon and nutrients as nitrogen (N) phosphorus (P) and potassium (K) was evaluated. The potential of N mineralisation of whole slurries, and each fraction after soil application, was assessed. Results of the study showed that the characteristics of the slurry fractions obtained depend strongly on the slurry type considered, namely on its dry matter (DM) content. A positive value of PNM was observed with the 3 slurry types and 4 fractions considered, indicating that no N immobilisation occurred. Nevertheless, results showed that the value of PNM vary significantly ($P < 0.05$) with slurry types and slurry particle size fractions.

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1. Introduction

Animal slurries are widely applied to soil as organic fertilisers to supply nutrients (N, P and K) to plants. However, animal slurries contain a large part of organic N that has to be mineralised prior to plant uptake (Rees & Castle, 2002). Furthermore, in countries with intensive livestock production, it may be necessary to export slurry to others farms that specialise in crop cultivation. Hence, it may be of interest to concentrate nutrients in order to increase the fertiliser value of slurry and decrease transport costs. In order to improve slurry management in terms of nutrients utilisation and decrease the environmental impact associated to slurry handling, mechanical slurry separation has been widely used in Asia (Hjorth et al., 2010). However, such practise is less developed in Europe and North America where slurry treatment is still considered as increasing in production costs (Petersen et al., 2007). Slurry separation leads to an organic nutrients rich solid fraction that may be composted and a liquid fraction that may be used for fertigation. The particle size of the slurry fractions obtained depends on the type of the mechanical separation technique (centrifugation, screening, or screw-press), the sieve mesh size and the slurry type (Burton & Turner, 2003; Hjorth et al., 2010). Previous studies (Møller, Sommer, & Ahring, 2002; Reimann, 1989) showed that slurry centrifugation allows removing all the >20–25 μm particles from the liquid fractions. However, a larger range of slurry particle sizes (0.7–3.2 mm) can be separated using screw-press or press

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Nomenclature

NH_4^+ (g kg^{-1}) ammonium
R^2 coefficient of determination
DM (g kg^{-1}) dry matter
LSD least significant difference
NO_3^- (mg kg^{-1}) nitrate
Norg (g kg^{-1}) organic nitrogen
OM (g kg^{-1}) organic matter
PNM (% of Ntot or % of N org) potential of N mineralisation
Ntot (g kg^{-1}) total nitrogen
TOC (g kg^{-1}) total organic carbon

auger (Hjorth et al., 2010). However Fangueiro, Chadwick, Dixon, and Bol (2007) reported that the amount of the cattle slurry particles size <45 μm represents more than 50 % of the total weight of slurry whereas particles size >2 mm represent 10–15%. However, Møller et al. (2002) following slurry separation by screw-press, obtained an amount of particle size fractions >1 mm equivalent to only ≈5% and 2–5% (m/m) in pig and cattle slurry, respectively.

Some new separation processes, combining mechanical separation with chemical additives such as coagulants or flocculants (Fangueiro, Pereira, et al., 2008; García, Szogi, Vanotti, Chastain, & Millner, 2008; González-Fernández, Nieto-Diez, León-Cofreces, & García-Encina, 2008; Vanotti et al., 2002), have been recently proposed in order to obtain a finest liquid fraction of slurry improving the efficiency obtained with mechanical separation.

In the present work, three types of slurry were studied and each one was separated by sieving into 4 slurry particle size fractions. The composition in terms of carbon and nutrients (N, P and K) of the whole slurries and slurry fractions was evaluated. The potential of N mineralisation (PNM) of whole slurries and slurry fractions after incorporation to soil was also assessed.

2. Material and methods

Three different slurries – pig, cow and duck, – were obtained in commercial farms. Each of the slurries was separated into four particle size fractions (>2000 μm, 2000–500 μm, 500–100 μm, <100 μm) by sieving. These size fractions were chosen in agreement with the size fractions used in other studies (Bol, Moering, Preedy, & Glaser, 2004; Doublet et al., 2009; Fangueiro et al., 2007). All the particle size fractions and whole slurries were characterised using the following procedures: total N content by the Kjeldhal method (Horneck & Miller, 1998). Mineral N content by extraction with 2 M KCl (1:5 w/v) (Mulvaney, 1996) followed by ammonium (NH_4^+-N) and nitrate (NO_3^--N) quantification by molecular absorption spectrophotometry in a Skalar segmented flow analyser using the Berthelot and sulphanilamide methods, respectively (Houba, van der Lee, Novozamsky, & Walinga, 1988, chap. 15.1); dry matter (DM) by drying 100 g of fresh material in a heater at 105 °C to constant weight for at least 24 h; organic matter (OM) by loss-on-ignition after incineration of the samples in a furnace at 500–550 °C during 24 h and total organic carbon (TOC) was estimated from the OM value using the conventional “Van Bemmelem Factor” of 1.724 (OM = TOC × 1.724) obtained by assuming that the medium C content in the OM is 58% (Tiquia & Tam, 2000); total potassium (K) content was quantified after hydrochloric acid (HCl) treatment of the ash in an atomic absorption spectrophotometer (PU 9000; PYE-Unicam Ltd, Cambridge, UK) and total phosphorous (P) was determined using the ammonium vanadomolybdate method and a molecular absorption spectrophotometer (U 2000; Hitachi, Tokyo, Japan).

Anaerobic incubation (Fangueiro, Bol, & Chadwick, 2008) was carried out to assess the potential N mineralisation of the slurry fractions and whole slurries. Specific amounts of slurry or slurry fraction corresponding to 0.02 g of N were added to 10 g of field-moist soil in a 60 mL syringe. The amount of water was set to have a total water amount of 25 mL in the mixture soil – slurry. The soil used was a sandy-loam soil. Ten replicates for each whole slurry or slurry fraction were constructed. Five were extracted immediately after the injection of 25 ml of 4 M KCl into each syringe to give a 1:5 ratio of (soil + slurry) to 2 M KCl; after 1 h shaking, the suspensions were filtered and the filtrates analysed for NH_4^+-N content. The other five replicates were incubated for 7 d at 40 °C. The extraction method described above was used at day 7 of the incubation period. Treatments with soil only were run as controls. Potential of N mineralisation (PNM) was calculated using the following equation:

$$PNM = \{([NH_4^+]_{t=7} - [NH_4^+]_{t=0})_{sample} - ([NH_4^+]_{t=7} - [NH_4^+]_{t=0})_{control}\}/Napplied \times 100$$

and was expressed as a percentage of the total N applied, PNM (Ntot), and as a percentage of the organic N applied, PNM (Norg).

Results from PNM were analysed by analysis of variance (one way-ANOVA). The statistical significance of the mean differences was determined by the least significant difference (LSD) tests based on a *t*-test at a 0.05 probability level.

3. Results and discussion

The three slurries used here varied significantly ($P < 0.05$) in terms of their total N, organic C and DM content (Table 1). A strong variation of slurry composition and quality as soil amendment has been observed in previous studies and attributed mainly to the animal diet, production systems, slurry treatment and storage (Burger & Venterea, 2008). The relative proportion of the slurry fractions used varied significantly depending on the slurry type considered. Indeed, in the pig and duck slurries that had lower DM contents relative to the cow slurry, the <100 μm fraction represented more than 98% of the whole slurry whereas the cow slurry contained a higher amount of coarser slurry particles. Previous studies (Møller et al., 2002; Sommer et al., 2008) showed that the slurry

Table 1 – Main characteristics of pig, cow and duck whole slurry and slurry fractions; mean value and standard error of 4 replicates.

	Relative proportion (%)	Total N (g kg^{-1})	Organic N (g kg^{-1})	NH_4^+-N (g kg^{-1})	NO_3^--N (mg kg^{-1})	Total organic C (g kg^{-1})	C:Norg ratio	C:N ratio	Total P (g kg^{-1})	Total K (g kg^{-1})	DM (g kg^{-1})
Pig											
Whole slurry	100.0	3.1 ± 0.0	0.3 ± 0.0	2.8 ± 0.0	0.4 ± 0.2	6.5 ± 0.3	20.8 ± 1	2.1 ± 0.1	0.3 ± 0.1	1.7 ± 0.0	17.6 ± 0.5
>2000 μm	0.4	7.8 ± 0.1	5.3 ± 0.2	2.5 ± 0.1	0.3 ± 0.1	93.1 ± 4.7	17.6 ± 0.6	12.0 ± 0.6	2.6 ± 0.1	1.6 ± 0.0	189.4 ± 9.2
500–2000 μm	0.9	5.7 ± 0.1	3.3 ± 0.2	2.4 ± 0.1	0.6 ± 0.1	71.4 ± 1.0	21.7 ± 0.9	12.5 ± 0.1	1.7 ± 0.1	1.9 ± 0.1	140.6 ± 1.8
100–500 μm	0.8	5.9 ± 0.1	3.3 ± 0.2	2.7 ± 0.1	0.3 ± 0.1	56.5 ± 0.0	17.3 ± 1.3	9.5 ± 0.2	2.1 ± 0.1	1.9 ± 0.1	119.7 ± 0.3
<100 μm	97.9	3.2 ± 0.0	0.1 ± 0.1	3.1 ± 0.0	0.8 ± 0.5	6.9 ± 0.0	55.7 ± 16.7	2.1 ± 0.0	0.3 ± 0.0	1.7 ± 0.1	15.0 ± 0.0
Cow											
Whole slurry	100.0	4.0 ± 0.2	2.1 ± 0.2	1.8 ± 0.0	0.3 ± 0.2	52.1 ± 3.6	24.8 ± 2.8	13.1 ± 1.1	0.9 ± 0.0	2.3 ± 0.1	118.8 ± 7.9
>2000 μm	55.5	3.8 ± 0.1	2.5 ± 0.1	1.2 ± 0.0	0.3 ± 0.2	73.3 ± 0.5	29.0 ± 1.0	19.5 ± 0.4	1.0 ± 0.0	2.4 ± 0.1	167.3 ± 0.2
500–2000 μm	21.4	3.5 ± 0.1	2.1 ± 0.0	1.5 ± 0.0	0.5 ± 0.1	60.4 ± 0.4	29.1 ± 0.8	17.1 ± 0.4	1.0 ± 0.0	2.5 ± 0.1	159.0 ± 0.8
100–500 μm	11.4	3.7 ± 0.0	2.5 ± 0.0	1.2 ± 0.0	0.5 ± 0.1	46.8 ± 0.0	18.6 ± 0.3	12.7 ± 0.0	1.6 ± 0.0	2.5 ± 0.0	148.4 ± 0.4
<100 μm	11.7	3.4 ± 0.0	1.6 ± 0.0	1.8 ± 0.0	0.4 ± 0.2	21.7 ± 0.1	13.7 ± 0.4	6.4 ± 0.1	0.7 ± 0.0	2.8 ± 0.0	60.4 ± 0.0
Duck											
Whole slurry	100.0	2.6 ± 0.0	0.7 ± 0.0	1.9 ± 0.0	0.1 ± 0.1	6.5 ± 0.1	9.6 ± 0.6	2.5 ± 0.0	0.6 ± 0.0	2.3 ± 0.1	19.0 ± 0.2
>2000 μm	1.5	12.4 ± 0.1	11.1 ± 0.1	1.4 ± 0.1	0.5 ± 0.1	65.8 ± 2.6	5.9 ± 0.2	5.3 ± 0.2	6.5 ± 0.4	2.2 ± 0.1	154.9 ± 5.9
500–2000 μm	0.4	9.2 ± 0.4	7.6 ± 0.4	1.6 ± 0.0	0.2 ± 0.1	51.2 ± 1.0	6.8 ± 0.4	5.6 ± 0.2	2.3 ± 0.1	2.4 ± 0.1	107.1 ± 2.1
100–500 μm	0.4	7.4 ± 0.1	5.8 ± 0.1	1.6 ± 0.0	0.4 ± 0.3	45.2 ± 0.4	7.8 ± 0.0	6.1 ± 0.0	3.1 ± 0.1	2.1 ± 0.0	100.2 ± 0.5
<100 μm	97.7	2.3 ± 0.0	0.3 ± 0.2	2.2 ± 0.2	0.3 ± 0.1	4.3 ± 0.0	15.1 ± 0.6	1.9 ± 0.0	0.3 ± 0.0	2.4 ± 0.0	16.7 ± 0.0

particle size fraction <25 μm contained approximately 70% and 50% of the total DM in pig and cattle slurry, respectively. Although here the pig and duck slurry was mainly composed of particles <100 μm, the three other fractions were also considered because in duck and pig slurries with higher DM contents such fractions could be more significant and consequently, information relative to these fractions is of interest. Furthermore, a mesh size of 0.25 mm is recommended to efficiently remove nutrients (N and P) to the solid fraction as well as and the main components responsible for odour (González-Fernández et al., 2008). Hence, it was of interest to obtain slurry fractions in a range including this mesh size.

The total N and organic N contents were generally higher in the largest slurry fractions relative to the finest one in the pig and duck slurries but in the cow slurry such differences were not so evident. Møller et al. (2002) also obtained higher total N concentration in the solid fraction (largest particle size) of cattle and pig slurry than in the liquid fraction (finest particle size). As expected, the DM and (TOC) contents of the slurry fractions decrease with the particle size for the three types of slurry considered. In the pig and duck slurries, the amounts of total organic C and DM in the finest slurry fraction were 10–15 times lower than the amounts observed in the other particle size fractions. This is in agreement with earlier results reported by Fangueiro et al. (2007) who observed similar relationships between the particle size fractions of cattle slurry and the TOC contents. A large amount of the total N was present in the ammoniacal form in the three whole slurries whereas the amount of nitrate was always lower than 1 mg NO_3^--N kg^{-1} (Table 1). Nevertheless, the NH_4^+-N: total N ratio was significantly ($P < 0.05$) higher in the pig and duck slurries relative to the cow slurry. The increased availability of NH_4^+ observed in the pig and duck slurries is important and valuable in those situations that require a rapid supply of nitrogen to plants. However, if manure is applied well in advance of its use by plants, this may be disadvantageous since a large amount of NH_4^+ will potentially be nitrified and subsequently lost by leaching with negative environmental impact.

Furthermore lower amounts of organic carbon were observed in the duck and pig slurry relative to cow slurry that is consistent with the low DM content of these 2 slurries. For each slurry type, the total P content of the finest fraction is significantly lower ($P < 0.05$) than in all other particle size fractions except in the case of the cow slurry but the total K content was similar in all slurry fractions.

The variability within each type of animal slurry in terms of components and nutrients affects directly N dynamics in amended soils and consequently N uptake by the plants as well as N losses to the environment. Indeed, for the whole slurry, the higher values of PNM (Ntot) and PNM (Norg) were observed in the pig slurry and the lower in the duck and cow slurries (Fig. 1). High values of PNM (Ntot) were generally obtained with the 100–500 μm and 500–2000 μm slurry fractions but the higher values of PNM (Norg) were observed in the finest particle size fraction (<100 μm) in the case of duck and pig slurries and in the 100–500 μm and 500–2000 μm fractions of cow slurry. Similarly, Fangueiro, Bol et al. (2008) observed a negative correlation between the PNM (Ntot) and the particle size of cattle slurry. Hence, obtaining a very fine fraction (<100 μm) of pig or duck slurry should be of interest for production of crops with high demands of mineral N in short time intervals after amendments application to soil whereas in the case of cow slurry, a separation at 2000 μm should be enough.

Despite the high variations observed between slurries and slurry fractions in terms of C:N ratio, N mineralisation was observed in all whole slurries and slurry fractions (Fig. 1). A positive correlation was observed between the C:N ratio and the PNM (Ntot) only in the case of pig slurry fractions (coefficient of determination (R^2) = 0.985). A negative correlation was

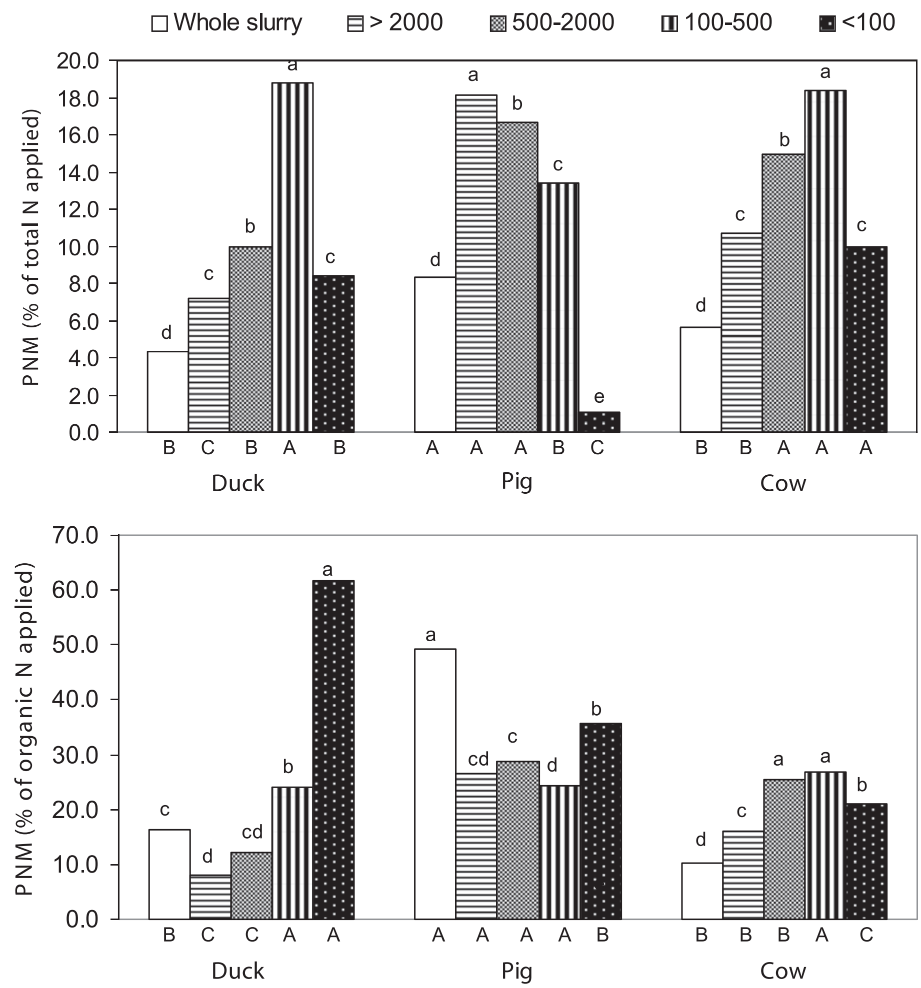

Fig. 1 – Potential nitrogen mineralisation (PNM) from the whole slurries and slurry fractions expressed as % of total N applied or % of organic N applied ($N = 5$). Values marked by the same letter are not significantly different ($P < 0.05$) between specific slurry type (capital letters) or fraction (normal letters) by LSD test.

also observed between the C:N ratio and the PNM (Norg) in the case of the duck ($R^2 = 0.981$) and pig ($R^2 = 0.636$) slurry fractions. This result contradicts the previous results reported by Chadwick, John, Pain, Chambers, and Williams (2000) who suggested that materials with lower C:N ratio led to N mineralisation whereas higher C:N ratios led to N immobilisation.

Our results show that in the case of slurries with low DM contents (pig and duck), slurry separation into 2 fractions >2000 μm and <2000 μm should allow the removal of most solids from the liquid fraction making easier its application to soil by injection or by umbilical systems. However, in such cases, separation does not lead to an efficient removal of total N and total P from the liquid fraction. The removals of N and P from the pig and duck slurries observed here were in the range of values (4–31% for total N and 7–46% for total P) obtained by screw-press with filter pore sizes of 0.7–1 mm (Hjorth et al., 2010). Furthermore, Vanotti and Hunt (1999) considered that most of the equipment available for slurry separation was not efficient for nutrient removal (N, P, K) because most of these nutrients are found in the fine particles in suspension. Indeed, our results showed that even screening at 100 μm was not enough to remove significant amounts of N and P. For slurries with higher DM contents (cow slurry), it is necessary to consider a separation at a finer mesh size to efficiently remove most of the total P and total N from the finest liquid fraction. Such a solution could be of interest if the liquid fraction is used for fertigation since such practise requires low concentrations of N and P in the solution. Nevertheless, it should be borne in mind that technologies to achieve such separation efficiency are expensive and more energy consuming.

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