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Band application of treated cattle slurry as an alternative to slurry injection: Implications for gaseous emissions, soil quality, and plant growth

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ABSTRACT

Animal slurry injection is considered the most effective solution to minimize ammonia (NH_3) emissions at the field scale, but band application of slurry treated by acidification and/or solid–liquid separation may be a good alternative. The main objective of our study was to compare the overall efficiency of band application of acidified cattle slurry (Band-ARS), the liquid fraction (Band-LF), or acidified LF (Band-ALF) relative to raw cattle slurry injection (RSI). Two control treatments were also considered: the traditional broadcast application of raw slurry, immediately followed by soil incorporation (Broad-RS), and an unfertilized plot (CTR). A field experiment was performed to follow NH_3, nitrous oxide (N_2O), and methane (CH_4) emissions, quantify plant yields and slurry nutrients use efficiency, and assess the impact on soil quality with special emphasis on enzymatic activity.

Our results show that Band-ARS led to NH_3, N_2O and CH_4 emissions similar to RSI while higher NH_3 emissions were observed in the Band-LF treatment relative to RSI. A decrease in crop yields was detected for the Band-ALF treatment, relative to RSI, but no significant ($P > 0.05$) differences were found between the other treatments considered.

Application to soil of acidified materials had no negative impact on enzymatic activity or soil characteristics, when compared to CTR. Overall, band application of acidified slurry appears as a good alternative to slurry injection.

1. Introduction

Cattle slurry application to soil is a traditional practice in most dairy farms as it ensures efficient cycling of nutrients, by combining slurry management/reuse and soil fertilization. Over recent decades, an industrialization and concentration of dairy farms in specific areas has been observed in many countries, leading to an increase in the amount of slurry produced and then applied to agricultural soils in restricted areas (FAO, 2009). It is well known that slurry application to soil may have a strong impact on the environment, in the form of ammonia (NH_3) and greenhouse gases (GHG) emissions and/or nitrate leaching and surface runoff of some nutrients and metals, if the most adequate technique for slurry application to soil is not used (Oenema et al., 2007; Webb et al., 2010). Today, slurry injection is the most recommended technique in some countries, but there are some limitations that hamper its implementation, namely: (a) it requires strong investment in machinery and increased energy consumption; (b) it is not applicable in stony or loamy soils; and (c) it is not applicable in small plots (Hansen et al., 2003; Huijsmans et al., 1998; Jensen, 2013; Rodhe and Rammer, 2002; Rodhe and Etana, 2005). Alternatives to slurry injection have been requested by farmers, to utilize slurry efficiently. Slurry pre-treatment, by solid-liquid separation and/or acidification, followed by band application is an interesting solution since it avoids or minimizes most of the limitations previously enounced.

Slurry acidification with sulfuric acid, used at a real scale in many Danish farms, has proven to be an efficient solution to minimize NH_3 losses from the raw slurry (RS) management chain—with a decrease in NH_3 emissions of 50–90% during storage and 60–85% after soil application, relative to RS (Bittman et al., 2014; Fangueiro et al., 2015a; Frost et al., 1990; Kai et al., 2008). Some studies indicate that application of acidified raw slurry (ARS) to soil might also minimize methane (CH_4) emissions (Petersen et al., 2012), but this may lead to an increase of nitrous oxide (N_2O) emissions, relative to RS, if nitric acid is

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used (Velthof and Oenema, 1993). However, Fangueiro et al. (2010) observed a decrease of N_2O emissions when slurry acidified with sulfuric acid was applied to a sandy soil, relative to RS-amended soil. A positive impact of slurry acidification on plant yields and the mineral fertilizer equivalent of slurry was also reported in previous field experiments (Kai et al., 2008; Sørensen and Eriksen, 2009) established in Denmark, but data are scarce regarding the efficiency of slurry acidification in Mediterranean countries—where the soils and climatic conditions are very different from Denmark. Furthermore, the impact of ARS application on soil microbial activity remains unclear (Fangueiro et al., 2015a). It is of note that the potential of slurry acidification as an abatement technique to reduce NH_3 emissions has also been questioned by the UNECE Task Force on Reactive Nitrogen, due to risks associated with organic acids manipulation and eventual pollution swapping (Bittman et al., 2014).

Solid–liquid separation is a useful tool to produce a nutrients-enriched solid fraction, that can be exported from the farm, and a liquid fraction (LF) that can be applied to soil at the farm scale. Application of the resulting LF, rather than RS, has also proved to be an efficient solution to minimize NH_3 emissions at the field scale (Hou et al., 2015). Indeed, the lower dry matter content and viscosity of LF – compared to RS – can, in some conditions, favor soil infiltration and lead, consequently, to lower NH_3 emissions (Nyord et al., 2012; Sommer and Hutchings, 2001; Sommer et al., 2006). Therefore, band application of LF could make the subsequent soil incorporation, required when using RS, unnecessary. Furthermore, LF has a low P content and high NH_4^+:N ratio, allowing application of higher amounts of plant-available N with no excess of P (Hjorth et al., 2010). Nevertheless, the high NH_4^+:N ratio of LF might also enhance NH_3 emissions if the weather and soil characteristics do not favor infiltration in the soil.

However, soil application of ARS or LF, intended to decrease NH_3 emissions, can lead to an increase of N_2O emissions or nitrate leaching—which might result in pollution swapping (Chadwick et al., 2011; Powell et al., 2011; Webb et al., 2010). Furthermore, soil application of ARS or LF might affect the soil microbial population and enzymatic activities or alter some of the main soil characteristics (pH, electrical conductivity, metal concentrations). Therefore, a proper and integrated evaluation of these new solutions is needed at the field scale.

A lack of data relating to the soil application of ARS and LF has limited the implementation of these strategies at the farm scale (Fangueiro et al., 2015a,b). However, the assessment of the global impact of these approaches requires long-term experiments, which might delay the transfer of information to farmers and stakeholders. For this reason, short-term experiments are useful tools to provide a preliminary assessment of the potential of the new strategies for slurry management. Indeed, even if changes in total soil organic matter are experimentally detectable only over prolonged time periods, the influence of soil management systems on microbial processes can be observed over a shorter time scale (Dick, 1994).

Thus, the scope of the present work was mainly a preliminary and integrated evaluation of the ability of the band application of ARS, LF, or ALF – as an alternative to slurry injection – to supply plant nutrients with low impact on the environment. With this purpose, a five-month, field-scale experiment was carried out to assess the effect of each treatment on NH_3 and GHG emissions, plant growth and slurry nutrients use efficiency, and soil quality—with special emphasis on enzymatic activity.

2. Material and methods

2.1. Experimental site

The present study was performed in an agricultural area located at Palmela, Portugal (N 38.57957; W 8.82954). The soil has a sandy texture and was classified as Haplic Arenosol (IUSS, 2006). The main characteristics of the 0–20 cm soil layer are shown in Table 1. The soil had not received any fertilization in the preceding 10 years.

The data of precipitation and minimum and maximum air temperature recorded on-site during the experiment are shown in Fig. 1. The climatic conditions observed during the experiment are typical of this region, according to records from the last 50 years.

2.2. Slurry treatment and main characteristics of the products used

Cattle slurry was sampled in a commercial dairy farm located close to the experimental field. The stored slurry was stirred for one hour prior to sampling, to ensure homogeneity. The slurry was stored in plastic barrels and left outdoors, loosely covered, until further treatment and utilization. Before each treatment (separation or acidification) or sampling, the slurry was stirred manually until a homogeneous material was obtained.

The LF was obtained by mechanical separation of the slurry using a screw-press. This separation technique is the most commonly used in Portugal. Both the RS and LF were then divided into two parts: the first was kept untreated and the second was acidified to pH 5.5 by addition of concentrated sulfuric acid, as described in Fangueiro et al. (2013). Acidification was performed one day before soil application and the pH was measured immediately before application.

The RS and LF and the respective acidified materials, ARS and ALF, were fully characterized and the main characteristics are shown in Table 2.

2.3. Experiment setup

A completely randomized design with three replicates was used, with the following treatments: injection at 5–7 cm depth of RS (RSI), band application of ARS (Band-ARS), band application of LF (Band-LF), and band application of ALF (Band-ALF). Two control treatments were also considered: the traditional broadcast application of raw slurry immediately followed by soil incorporation (still extensively used in Southern Europe) (Broad-RS), and an unfertilized plot (CTR). This led to a total of 18 individual field

Table 1
Main characteristics of the soil used ($N = 3$).

Parameters	
Particlesizedistribution	
Clay (g kg^{-1})	33
Silt (g kg^{-1})	45
Sand (g kg^{-1})	922
Organic matter (g kg^{-1})	20.8
pH (KCl)	5
Total N (g kg^{-1})	0.98
Olsen P (mg kg^{-1})	135.4
Na (cmol$_+$kg^{-1})	0.105
K (cmol$_+$kg^{-1})	0.33
Mg (cmol$_+$kg^{-1})	0.57
Ca (cmol$_+$kg^{-1})	2.271
Cu (mg kg^{-1})	8.6
Zn (mg kg^{-1})	10.9
Fe (mg kg^{-1})	151.4
Mn (mg kg^{-1})	12.7
Dehydrogenase (μg TPF g^{-1}24 h^{-1})	129
β-glucosidase (μg p-nitrof.g^{-1} h^{-1})	134.3
Acidphosphatase (μg p-nitrof.g^{-1} h^{-1})	643.5
Alkaline phosphatase (μg p-nitrof.g^{-1} h^{-1})	93.7
Urease (μg N-NH_4^+ g^{-1} 2 h^{-1})	7.7
Argininedeaminase (μg N-NH_4^+ g^{-1}3 h^{-1})	2.9
Nitrificationpotential (μg N-NO_2^- g^{-1}5 h^{-1})	0.507