Agriculture, Ecosystems and Environment 267 (2018) 87–99

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

# Band application of acidified slurry as an alternative to slurry injection in a Mediterranean double cropping system: Agronomic effect and gaseous emissions

David Fangueiro[a,*], José L.S. Pereira[b,c], Irene Fraga[b], Sónia Surgy[a], Ernesto Vasconcelos[a], João Coutinho[d]

[a] LEAF, Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal
[b] CITAB, University of Trás-os-Montes and Alto Douro, Quinta de Prados, 5000-801 Vila Real, Portugal
[c] CI&DETS, Escola Superior Agrária de Viseu, Instituto Politécnico de Viseu, Quinta da Alagoa, 3500-606 Viseu, Portugal
[d] Centro de Química, University of Trás-os-Montes and Alto Douro, Quinta de Prados, 5000-801 Vila Real, Portugal

## ARTICLE INFO

*Keywords:*
Acidification
Gaseous emissions
Organic fertiliser
Oat
Maize
Injection
Cattle slurry
Nutrient recovery

## ABSTRACT

Injection is the recommended technique for slurry application to soil in most European countries but its utilization at the farm scale is quite limited, namely in countries from southern Europe, due to the strong investment needed in machinery and problematic utilization in stony and/or heavy soils. Acidification of animal slurry has proved to be efficient at minimising $NH_3$ emissions but little is known about its impact on other greenhouse gas (GHG) emissions or agronomic effect, particularly in Mediterranean conditions. In the present study, we evaluate the potential of band application of acidified slurry as an alternative to raw slurry injection, in terms of agronomic effects and $NH_3$ and GHG emissions, for two different Mediterranean soils (a sandy and a sandy-loam soil) where a double-cropping system (oat during winter and maize during spring/summer) was run over 3-years. Five treatments were tested in 1 $m^2$ field plots: 1) control (non amended soil); 2) injected slurry (IS); 3) band application of raw slurry followed by soil incorporation (SS); 4) band application of acidified slurry followed by soil incorporation (AS); 5) band application of acidified slurry with no soil incorporation (ASS). An amount of slurry equivalent to ~90 and 170 kg N $ha^{-1}$ was applied before oat and maize sowing, respectively.

The dry matter yields obtained with the AS treatment, in both the maize and oat crops, were mostly similar to or higher than those of IS, while ASS led - on some occasions - to small decreases in dry matter yield relative to IS, namely in the sandy soil. Treatment AS led also to apparent N and P recovery values (ANR and APR, respectively) similar to or higher than those of IS, except in the sandy soil during oat growth. After six consecutive slurry applications, a significant decrease of pH and an increase of the extractable S content were observed in soil receiving acidified slurry, relative to soil amended with non-acidified slurry.

Significant $NH_3$ emissions were observed only in SS treatment during all the experiment. Of the total N applied, the amount lost as $N_2O$ did not differ significantly among the amendment treatments during the oat growth. However, the cumulative $N_2O$ emissions from IS were significantly higher, relative to SS, AS and ASS, during maize growth. Higher cumulative $CH_4$ emissions were observed during maize growth relative to oat growth, namely from IS compared to all other treatments. Band application of acidified slurry without soil incorporation reduced the $N_2O$ and $CH_4$ emissions by 65% and 40%, respectively, relative to IS. The soil characteristics had no significant effect on the gaseous emissions for the acidified slurry treatments.

It can be concluded that band application of acidified slurry followed by soil incorporation is an efficient solution to provide nutrients to plants while minimising $NH_3$ and GHG emissions and can thus be proposed as an alternative to injection. Nevertheless, the impact of acidified slurry application on soil properties needs to be monitored in the long term.

* Corresponding author.
*E-mail address:* dfangueiro@isa.ulisboa.pt (D. Fangueiro).

https://doi.org/10.1016/j.agee.2018.08.011
Received 18 December 2017; Received in revised form 9 August 2018; Accepted 12 August 2018
0167-8809/ 

## 1. Introduction

Dairy cattle production in some European countries has been forced to undergo an important concentration and industrialization, resulting in a significant production of manure, namely slurry (liquid manure) that is now close to 55 million tonnes per year in Europe (Foged et al., 2011).

Dairy cattle slurry is traditionally applied to agricultural soil as a source of nutrients and, over the last decade, the use of dairy slurry has been promoted as a substitute for or complement to mineral fertilizer in order to decrease production costs and increase nutrients recycling at the farm scale.

The Portuguese dairy cattle production is concentrated in the North West region, where a double cropping system is traditionally used (Fangueiro et al., 2008). A spring/summer crop (mainly maize silage) is grown from April to the end of August and a second crop (oat or ryegrass) is grown from October until March. Before each crop, cattle slurry is applied as a basal fertilization that enables dairy farmers to apply most of the slurry produced during the growing period. This double cropping system is used in other European regions, such as Galicia (Spain) and the Po Valley (Italy) (Ovejero et al., 2016). The use of cattle slurry for partial or complete replacement of mineral fertilizer has been studied in different pedo-climatic conditions (Cavalli et al., 2016; Schröder et al., 2013) and the results show that this practice led to yields similar to those obtained with mineral fertilizers (Cavalli et al., 2016; Webb et al., 2013).

However, slurry management, namely during and after soil application, leads to emissions of carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$) and ammonia ($NH_3$), all with important impacts on climate change, acid rain and ozone formation in the troposphere (Sommer et al., 2013; Bittman et al., 2014). Among them, the greatest concerns are related to $NH_3$ emissions (Sommer et al., 2013) - which, besides decreasing the plant N use efficiency of animal slurry, have a strong impact on ecosystems (Bittman et al., 2014). Furthermore, the N:P ratio of the slurry does not match the N and P demands of the crops, leading to over-application of P when the application is based on N. Strict conditions for slurry application to soil have arisen in some European countries to minimize the associated environmental impact, namely gaseous emissions. The common solution to minimize $NH_3$ losses in many countries, such as Portugal and Spain, is based on slurry incorporation into the soil after its surface broadcasting application, but this incorporation has to be performed as soon as the application is done. However, this solution is not as efficient as slurry injection at minimising $NH_3$ emissions and cannot be applied in permanent grassland (Webb et al., 2014). Furthermore, surface broadcasting by a splash plate applicator, has been banned in some countries of Northern Europe due to its strong impact on $NH_3$ emissions (Webb et al., 2010).

For this reason, slurry injection into the 7–10 cm soil layer is today compulsory in several countries, since it reduces $NH_3$ emissions strongly compared to surface broadcasting (Carozzi et al., 2013; ten Hoeve et al., 2016). The impact of slurry injection on other gases, such as $N_2O$ and $CH_4$, is still not clear and previous studies led to contradictory results (Rodhe et al., 2006; Langevin et al., 2015). Indeed, Bhandral et al. (2009) concluded, from a field experiment, that slurry injection is efficient to minimize $NH_3$ emissions without increasing $N_2O$ emissions but recently, Duncan et al. (2017) reported that slurry injection lead to a significant increase of $N_2O$ emissions (84–1152%) relative to surface broadcast. Furthermore, slurry injection implies a strong investment in specialised machinery that requires more energy consumption and may not be applicable in stony soils and/or small plots (Webb et al., 2010).

More recently, slurry acidification before application to soil has been proposed as a solution to minimize $NH_3$ emissions during and after soil application by surface banding (Kai et al., 2008; Bittman et al., 2014; Fangueiro et al., 2015a, 2015b; Cocolo et al., 2016; Gómez-Muñoz et al., 2016). Furthermore, laboratory studies indicated that slurry acidification has also some impact on P availability to plants (Roboredo et al., 2012). Information about the impact of acidified slurry application to soil on $NH_3$ and greenhouse gas emissions in Mediterranean conditions is still scarce or non-existent (Fangueiro et al., 2015c, 2016). On the other hand, by minimising $NH_4^+$ losses, slurry acidification might lead to higher $N_2O$ emissions after soil application since more substrate will be available for nitrification and denitrification processes. Nevertheless, recent studies indicated that the nitrification process is inhibited or almost delayed in soil amended with acidified slurry relative to non acidified slurry (Fangueiro et al., 2016). Therefore, lower $N_2O$ emissions could be expected from soil amended with acidified slurry relative to non acidified slurry.

Our main hypothesis was that band application of acidified slurry is almost as efficient as slurry injection with regard to minimising $NH_3$ emissions without increasing $N_2O$ emissions. Hence, the main objective of the present work was to evaluate the potential of band application of acidified slurry as an alternative to raw slurry injection, in terms of agronomic effects and $NH_3$ and GHG emissions, for two different Mediterranean soils where a double-cropping system (oat followed by maize) was run over 3-years. Band application of raw slurry followed by incorporation was also considered, as the traditional method, and the impact of acidified slurry incorporation into soil following band application was also tested. The sub-objectives were: 1) to compare the fertilizing value of raw and acidified slurry; 2) to determine the impact of soil incorporation of acidified slurry on plant yield and nutrient removal; 3) to compare the effects of raw slurry injection and band application of acidified slurry on the agronomic value; 4) to assess the effects of the slurry management strategies tested here on general soil properties after three years of application.

## 2. Material and methods

### 2.1. Study site and soils characteristics

The present study was performed in lysimeters located at the experimental facilities of the Instituto Superior de Agronomia-Lisbon-Portugal (N 38.708098; W 9.185001). Thirty lysimeters (1 m × 1 m × 1 m) were used in this experiment, half of them containing a Haplic Arenosol with a sandy texture (70% coarse sand, 7% fine sand, 10% silt, 3% clay) and the other half containing a Haplic Cambisol with a sandy-loam texture (27% coarse sand, 56% fine sand, 7% silt, 10% clay) (WRB, 2015). The main characteristics of the 0–200 mm soil layer at the beginning of the experiment are shown in Table 1. The soils had not received any fertilization in the preceding five years and the 0–20 m mm soil layer of each lysimeter was mechanically homogenized before the beginning of the experiment.

The precipitation and minimum and maximum air temperature data recorded on-site during the experiment are shown in Fig. 1.

### 2.2. Raw and acidified slurry

The raw cattle slurry used in this study was sampled twice a year (in autumn and spring) in the same commercial dairy farm located near Palmela (Portugal) during the 3-year experiment. The dairy cows were fed with ryegrass or maize silage and concentrated feed.

Slurry was transported and kept at ambient temperature in plastic barrels (50 L) for approximately one week before application. In the 24 h before soil application of the treatments, raw slurry acidification was performed by addition of concentrated sulphuric acid (about 6 mL per L of slurry) to reach a final pH of 5.5, following the procedure described by Fangueiro et al. (2015b, 2015c). Representative samples of acidified and non-acidified cattle slurry were collected and then analysed for the characteristics shown in Table 2. The details of the standard analytical methods used to assess the physico-chemical properties of the soils and slurries studied are available in Fangueiro et al. (2015c).