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Anaerobic digestion coupled with digestate injection reduced odour emissions from soil during manure distribution

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HIGHLIGHTS

- Anaerobic digestion reduces odours impact because of degradation of organic matter.
- Anaerobic digestion (AD) coupled with manure injection reduced odour emissions.
- Specific Odour Emission Rate (SOER) well correlated with electronic nose fingerprint
- Electronic nose can replace SOER in measuring odour impact.

GRAPHICAL ABSTRACT

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ABSTRACT

This work aimed to measure the odour impact of untreated cow and pig slurries and treated (digestate and liquid fraction of digestate) manures when they were used on soil at a field scale, while also testing different spreading methods, i.e. surface vs. injection. Five experiments were performed in 2012–2016 on different farms. Odours were quantitatively (specific odour emission rate – SOER) ($OU_E\ m^{-2}\ h^{-1}$) measured by using dynamic olfactometry and qualitatively, i.e. to obtain an "odour fingerprint", by using an electronic nose (EN).

Anaerobic digestion was effective in allowing the reduction of potential odour emission from digestates, so that when they were dosed on soil, odours emitted were much lower than those from soils on which untreated slurries were used. Slurries/digestate injection reduced much more odour emitted by soils so that SOER tended to become more similar to that of the control (untreated soil) although the odours were slightly greater.

Odour fingerprint data indicated that there was a direct correlation between SOER and odour fingerprints. This was due to the ability of EN to detect ammonia, S-compounds and methane that were (the first two mainly), also, responsible for odours. Very good regression was found for Log SOER and EN by using a Partial Least Square (PLS) approach ($R^2 = 0.73$; $R^2_{cv} = 0.66$; $P < 0.01$) for matrices used to fertilize soils in lab tests. Unfortunately, regression was not so good when odour data from field experiments on soil were used, so that EN cannot be proposed to replace olfactometry. EN fingerprints for control (Blank) and injected organic matrices were virtually identical, due to the creation of cavities in the soil during the injection that decreased the treated surface. Anaerobic digestion and subsequent digestate injection allowed us to reduce odour impact, avoiding annoyance to local inhabitants.

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1. Introduction

Odour emissions constitute a problem when they affect public health because of the diffusion of diseases and nuisance to the surrounding population (Orzi et al., 2015). Land application of manure can be a major source of odour emission in rural communities (Parker et al., 2013). Manures emit odours, Volatile Organic Compounds (VOC) and non-VOCs (ammonia, hydrogen sulphide) that represent a concern for inhabitants close to field application sites (Parker et al., 2013).

In Europe, new legislation on environmental protection will require methods to reduce both ammonia and odour emission due to the spreading on the land of animal slurries (Pahl et al., 2001). Among different methods proposed to reduce emissions, slurry treatment through anaerobic digestion (Feilberg et al., 2015) and the direct injection of digestate into the soil have been proposed as successful practices (Riva et al., 2016).

Anaerobic digestion (AD) is a biological process that degrades organic matter contained in biomass under anaerobic conditions to produce biogas, a methane-rich gas, and a biologically stable high-value fertilizer product (Tambone et al., 2010), the digestate: this latter is used as a fertilizer at farm level (Riva et al., 2016). The degradation process, reducing the easily available organic matter through microorganisms' activities, also reduces the potential for producing odours by the digestate (Orzi et al., 2010).

Slurry spreading by injection is a method that uses devices capable of delivering the slurry directly into the subsoil, reducing the impact of odours during spreading (Pahl et al., 2001; Riva et al., 2016). Therefore coupling anaerobic digestion with digestate injection should reduce a lot of the odours' impact and so population annoyance and environmental problems, as well.

The increasing number of complaints about odours due to slurry spreading on the land had stimulated interest in odour measurement techniques to identify and verify suitable and reliable odour abatement techniques (Stuetz et al., 1999; Feilberg et al., 2015). Current methods to measure odours refer to the use of panels of odour assessors to determine human detection thresholds, i.e. dynamic dilution olfactometry (Stuetz et al., 1999). This measurement is time consuming, labour intensive, and it is carried out in specially designed odour laboratories that are often remote from the sampling sites (Misselbrook et al., 1997). Dynamic dilution olfactometry gives only a quantitative response to odours and it says nothing about the nature of odours. The evaluators are also subjected to inhalation of organic molecules of unknown origin and which may sometimes be toxic.

The availability of commercial electronic nose (EN) systems for odour detection and measurement may offer an alternative method for odours' assessment. These systems consists of an array of electronic chemical sensors specific for one or for a group of chemical molecules (Misselbrook et al., 1997), that can be used to produce a unique odour profile or "fingerprint" by successive elaboration of sensor signals through applying statistical/neural network algorithms (Stuetz et al., 1999). Therefore, electronic noses are useful to identify odours' fingerprints, giving, also, information about their chemical nature. On the other hand, EN does not allow us to obtain quantitative responses for the odours emitted, so that it cannot be used as a field method to measure the odours' impact.

Orzi et al. (2010) were able, by performing an experiment measuring odours emitted during anaerobic digestion, to find a very good linear regression between data on odours measured by using EN and data coming from the olfactometry methodology. Some authors proposed that after a correct calibration, the EN could replace olfactometry as a tool for odour impact measurement (Defoer et al., 2002).

In order to study at full scale the effect of both anaerobic digestion and different digestate spreading methods on odour impacts, in the years 2012–2016 a series of experiments was conducted at open field farm level within different research projects. In particular, digestates and the liquid fraction of digestates were used at field scale as fertilizers, substituting for mineral fertilizers (urea). While doing so, soils treated with digestates were compared with untreated soils and soils treated with urea and undigested slurries. The large amounts of full-scale data obtained throughout four years of research activity at five experimental sites have been brought together in this paper and critically discussed.

2. Material and methods

2.1. Experimental fields

A four-year field study was conducted in 2012–2013 and in 2015–2016 on five experimental agricultural fields cropped with corn silage in farms on which active anaerobic digestion plants were present. All the farms were located in the Lombardy Region (Italy).

Different fertilizer matrices, i.e. pig and cow slurries, digestate and the liquid fraction of digestate (organic fertilizers) were characterized for their potential odour emissions when considered both on their own in lab studies and later when they were applied to soils. Mineral fertilizers (urea) and untreated soil (Blank) were considered as well. Organic fertilizers (sometimes referred to as "matrices") were applied to the soil by both surface and injection methods. During spreading, odour emissions were sampled and analysed through the Dynamic Olfactometry, Electronic Nose (EN) and GC/MS methods.

Details of the experimental fields are as follows: *i.* Field A (in 2012) was a silty-clay irrigated (surface basin irrigation) soil of 7.4 Ha; plot area was 5300 m^2. The experimental design adopted was that of a "randomized block" with four treatments characterized by different fertilization regimes repeated twice (Table 1). In the same table (Table 1) it was reported, also, the total amount of nitrogen applied for each treatments, that was determined taking into consideration crops requirement. Pig slurries, used in the mix with energy crops in the AD, was also included as untreated biomass to be compared during the campaign with the biologically AD treated samples used to fertilize crops. The seedbed was prepared by minimum tillage and plant density was 8 plants m^{-2}. *ii.* Field B (in 2013) was a silty-clay irrigated soil (surface basin irrigation) of 7.5 Ha; plot area was 4500 m^2. The experimental design adopted was that of a "randomized block" with four treatments characterized by different fertilization regimes repeated twice (Table 1). Slurry, used in the mix with energy crops in the AD, was also considered as untreated biomass to be compared during the campaign with the biologically AD treated samples used to fertilize crops. The seedbed was prepared by soil ploughing and harrowing, and the plant density was 7.5 plants m^{-2}. *iii.* Field C (in 2012–2013) was a silty-clay soil irrigated by drip (first year) and by surface basin irrigation (second year) of 5.5 Ha; the experimental design adopted was that of a "randomized block" with four treatments characterized by different fertilization regimes repeated twice for eight plots of about 4000 m^2 each (Riva et al., 2016). Cattle slurry, used in the mix with energy crops in the AD, was also included as untreated biomass to be compared during the two treatments with the biologically AD treated samples used to fertilize crops (Table 1). The seedbed was prepared by soil ploughing and harrowing, and the plant density was 8 (first year) and 9.5 (second year) plants m^{-2}. *iv.* Field D (in 2015–2016) was a loamy irrigated (surface basin irrigation) soil of 7.5 Ha; plot area was 3.75 Ha each. The seedbed was prepared by a minimum tillage method and the density was 8 plants m^{-2}. *v.* Field E (in 2015–2016) was a clay-loam irrigated soil (surface basin irrigation) of 10 Ha; plot area was 5 Ha each. The seedbed was prepared by a strip till method and the plant density was 8 plants m^{-2}.

The experimental design aimed to study the odour impacts measured during the use of digestate or the derived liquid fraction at pre-sowing and top dressing fertilization, taking into consideration different organic fertilizers and spreading methodology. Doing so comparison with odours impact coming from the use of untreated animal slurry (both pig and cow slurry), urea and no fertilizer use (the control, i.e. Blank) was considered as well. Experimental design considered, also, the comparison of