doi: 10.17221/678/2016-PSE

Fertilizer type influences tomato yield and soil N_2O emissions

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ABSTRACT

Vitale L., Polimeno F., Ottaiano L., Maglione G., Tedeschi A., Mori M., De Marco A., Di Tommasi P., Magliulo V. (2017): Fertilizer type influences tomato yield and soil N_2O emissions. Plant Soil Environ., 63: 105–110.

Improvements in crop management for a more sustainable agriculture are fundamental to reduce environmental impacts of cropland and to mitigate effects on global climate change. In this study three fertilization types – ammonium nitrate (control); mineral fertilizer added with a nitrification inhibitor (3,4-dimethylpyrazole phosphate (DMPP)), and an organo-mineral fertilizer (OM) – were tested on a tomato crop in order to evaluate effects both on crop production and soil N_2O emissions. Plants grown under OM fertilization had a greater relative growth rate compared to mineral fertilization, due to a higher net assimilation rate, which was related to a greater light interception rather than to a higher photosynthetic efficiency. OM fertilization determined the highest fruit production and lower soil N_2O fluxes compared to NH_4NO_3, although the lowest soil N_2O fluxes were found in response to mineral fertilizer added with a nitrification inhibitor. It can be concluded that organo-mineral fertilizer is a better nutrient source compared to mineral fertilizers able to improve crop yield and to mitigate soil N_2O emission.

Keywords: plant growth; nitrous oxide; emission factor; Mediterranean climate

Intensive agriculture requires high energy inputs, which makes cropping systems among the most important sources of greenhouse gases. Arable soils contribute greatly to N_2O emission in the atmosphere, resulting the most important source of N_2O due to the large use of nitrogen (N) fertilizers in order to increase crop yields (Bell et al. 2015). N represents an essential nutrient for all crops being involved in many physiological processes related to dry matter production. Fertilizers supply greater than the crop demand can lead to nitrogen loss from soil due to NO_3^--N leaching and N_2O/NO production by microbial processes (i.e. nitrification and denitrification), with a negative impact on climate and environment.

Improved crop management techniques have been suggested to reduce the soil N_2O emission and to improve crop production (Rees et al. 2013, Snyder et al. 2014), including the use of fertilizer added with nitrification inhibitor (NI) (Ranucci et al. 2011, Vitale et al. 2013) and organic manure (Ball et al. 2004). The use of NI-added fertilizers offers several advantages compared to conventional ones because it increases fertilizer use efficiency with positive effects on plant growth and crop yields and inhibits NH_4^+-N oxidation, and in turn soil NO_3^--N content, thus limiting N_2O production. Organic manures, abounding in nutrients and labile carbon, have been widely used as soil fertilizers and

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amendments. Studies describe an enhancement of crops production and yield with organic fertilization, whereas contrasting results on the reduction in soil N_2O emission have been reported (Kaiser and Ruser 2000, Ball et al. 2004, Yao et al. 2015).

The use of fertilizer added with a nitrification inhibitor could offer advantages compared to organic manure under conditions favouring N_2O production. 3,4-dimethylpyrazole phosphate (DMPP) is a new generation nitrification inhibitor; it prevents NH_4^+-N oxidation due to nitrification and in turn maintains a low soil NO_3^--N concentration, which is needed for denitrification. Moreover, NH_4^+-N concentration under high soil water content is elevated when DMPP is applied on soil (Bart et al. 2008). This should benefit crop yield and limit N losses.

A study on the comparison of effects of mineral fertilization added with NI and organic fertilization on crop production and soil N_2O emission has been rarely performed, especially in agricultural systems of the Mediterranean area where abundant water is supplied by irrigation to crops to compensate the high air evaporative demand, thus favouring soil environmental conditions promoting N_2O production.

The goal of this work was to compare the effects of different fertilizers on crop production and soil N_2O emission from a tomato crop grown upon optimal water regime in Southern Italy under Mediterranean climate conditions.

MATERIAL AND METHODS

The experiment was carried out in Ponticelli (Naples), in Southern Italy, characterized by the Mediterranean climate with warm dry summers and mild wet winters. Soil texture is coarse due to its volcanic origin (Table 1). Tomato seedlings (*Solanum lycopersicum* L.) were transplanted on May 3, 2012 in rows spaced 1 m apart. Before transplanting, phosphorus (P) and potassium (K) fertilizers in the forms of calcium superphosphate and potassium sulfate were applied. The same total amount of 120 kg N/ha was applied twice to all plots along rows, split in two times: 50% at transplanting and 50% 30 days later. A randomized complete block experimental design with three fertilization treatments and three replications in 3 × 4 m plots was set up: ammonium nitrate (NH_4NO_3) (control plots); Entec 26 i.e. ammonium sulfate nitrate (26% N and 32% S) added with nitrification inhibitor (3,4 dimethylpyrazole phosphate, Entec©) (DMPP plots), and organo-mineral fertilization using dried pellets (OM plots). All plots were watered by drip irrigation, by replenishing water lost by evapotranspiration, according to reference evapotranspiration estimated by the Hargreaves equation.

Growth analysis. Three plants per plot were collected at 20 and 82 days after transplanting (DAT). All plant parts were transferred in an oven at 60°C up to constant weight. Green leaf area was determined by means of an area mater (Li-3000, Licor Inc. Lincoln, USA). The relative growth rate (RGR); the net assimilation rate (NAR); the specific leaf area (SLA); the leaf area ratio (LAR), and the leaf mass ratio (LMR) were calculated on the basis of leaf area and biomass data (Radford 1967). Fruits were periodically hand-picked as they reached maturity and final harvest took place on July 27 (82 DAT). On the same plants used for biometrical determinations, carbon and nitrogen content was determined in stems and leaves by means of a gas chromatography (CNS analyzer – Thermo Finnegan, Milan, Italy).

Soil N_2O emissions, soil sampling and analysis. Soil N_2O emissions were measured between the two fertilization events (0–30 DAT) by using 20 cm diameter and 10 cm height static chambers insert 3 cm into the soil and positioned at two different places: on the ridge and between furrows. Air samples were collected before and three times following chambers closure in a time window of 30 min by means of a polypropylene syringe, and stored in 0.02 L vials. Gas samples were analysed by means of a gas chromatograph (SRI 8610C, Gas Chromatograph, Torrance, USA) using a ^{63}Ni electron-capture detector.

Table 1. Soil chemical properties at 0–10 cm depth at the experimental site

Parameter	Value
Soil type	sandy
Texture (%):	
Clay	8
Silt	12
Sand	80
Bulk density (g/cm^3)	1.37
pH_{H_2O}	7.08
Electrical conductivity (mS/m)	14.9
Organic matter (g/kg)	2.54
Total nitrogen (g/kg)	1.86

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The N_2O flux was estimated as:

$$F_{N_2O\text{-}N}\ (\mu g/m^2/h) = h\ (m) \times dC\ (\mu g/m^3\ N_2O\text{-}N)/ /dt\ (h)_{t=0}$$

Where: h – height of chamber; C – N_2O concentration; t – time. dC/dt, i.e. the slope of the gas concentration curve, has been estimated by using a linear regression model. Only curves where the slope did not change sign over the observation period were taken into account, i.e.

$$dC/dt|_{t=0} / dC/dt|_{t=30} > 0 \text{ (Stolk et al. 2009).}$$

The N_2O emission factor (EF1) for each fertilizer was calculated according to IPCC (2007) as:

$$EF1\ (\%) = f_c\ (\mu g\ N_2O\text{-}N/m^2)/N\ (\mu g/m^2) \times 100$$

Where: f_c – cumulative flux calculated by linear interpolation; N – nitrogen amount supplied at transplanting.

Soil NH_4^+-N and NO_3^--N content, volumetric soil water content (SWC) and soil temperature (T_{soil}) were determined inside the chambers immediately after the flux measurement was completed. Soil samples were collected by 5 cm diameter cylinder and taken from the upper 0–10 cm layer inside chambers after N_2O measurements. Samples were air-dried and sieved (2 mm). NH_4^+-N and NO_3^--N content was determined in a 2 mol/L KCl soil extract (1:10 w/v ratio) and measured by the UDK 169 Automatic Kjeldahl analyzer. Both SWC and T_{soil} were determined at a depth of 0–10 cm by using a TDR (Tektronix 1502B Metallic Cable Tester, Refurbished, Melrose, Scottish) and a thermocouple, respectively. Water filled pore space (WFPS) was calculated by using the SWC and bulk density (BD), on the basis of an average apparent density of the soil matrix of 2.65 g/cm^3.

Statistical analysis. Statistical evaluation of data was performed by means of the Sigma-Plot graphical and statistical package (Sigma-Plot 12.2, Systat Software Inc. Release, San Joses, USA). Differences in plant growth and in C and N content were analysed by one-way ANOVA followed by the Duncan's test. Differences in soil N_2O fluxes between treatments and chamber position were checked by two-way ANOVA followed by the Duncan's test. Simple linear regressions were performed to assess the soil-related independent variables on soil gas emissions.

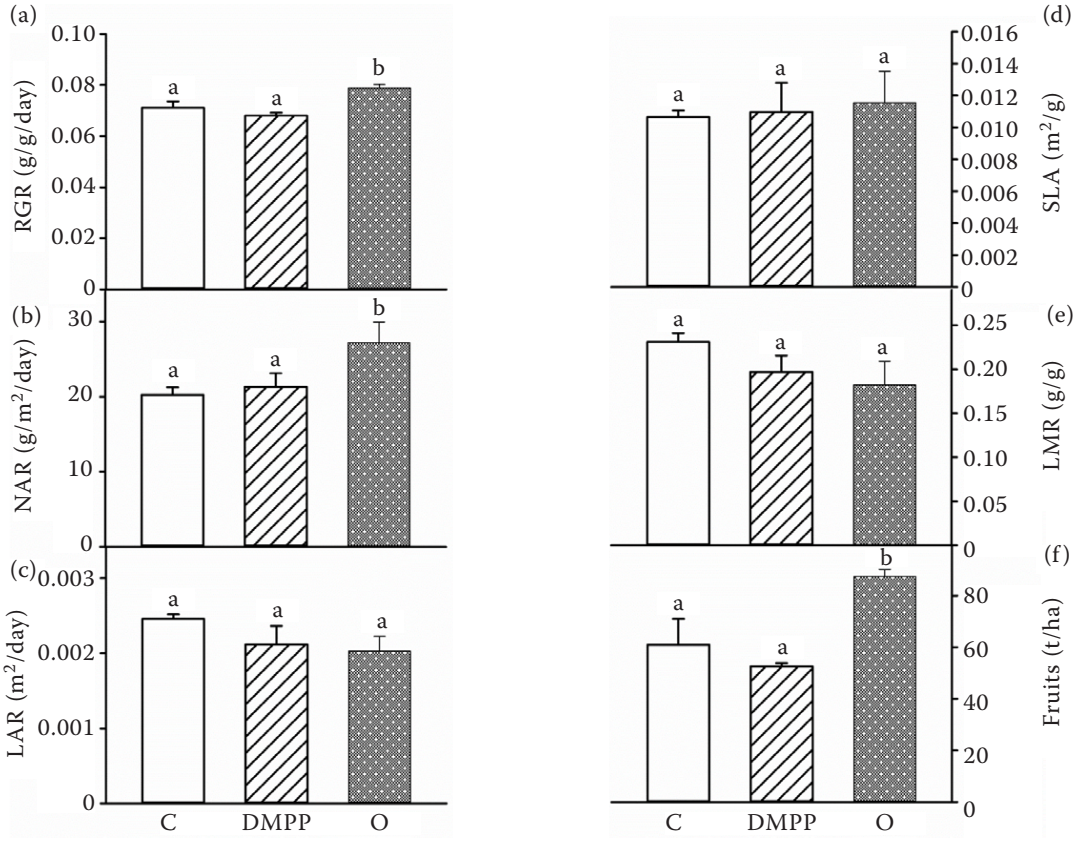

Figure 1. (a) Relative growth rate (RGR); (b) net assimilation rate (NAR); (c) leaf area ratio (LAR); (d) specific leaf area (SLA); (e) leaf mass ratio (LMR), and (f) fruit production for control (C), Entec (DMPP), and organo-mineral (O) plots. Data are means (n = 9) ± standard error. Different letters denote significant differences

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Table 2. Nitrogen (N) and carbon (C) content (g/kg) in stem and leaves of control, Entec (3,4-dimethylpyrazole phosphate (DMPP)), and organo-mineral plots. Data are means (n = 9) ± standard error

Treatment	Stems		Leaves	
	C	N	C	N
Control	402.0 ± 51.8	22.2 ± 03.1	295.3 ± 29.4	45.8 ± 7.0
DMPP	356.9 ± 38.7	18.6 ± 02.2	291.2 ± 56.2	53.6 ± 2.5
Organo-mineral	274.2 ± 64.6	16.5 ± 03.5	203.9 ± 20.0	35.3 ± 13.1

RESULTS AND DISCUSSION

Growth analysis and crop yield. The relative growth rate resulted highest ($P < 0.05$) in organo-mineral plots as compared to control and DMPP plots (Figure 1a). This was the result of higher net assimilation rate ($P < 0.05$) because the leaf area ratio was statistically similar among the three fertilization treatments (Figure 1b,c). The reason for the enhanced carbon gain by plant in OM plots could be related to a greater development of leaf area because the nitrogen content in leaves was statistically similar among treatments (Table 2), suggesting that the photosynthetic potential was the same for the plants grown upon different fertilizations. Moreover, a negative correlation was not observed between NAR and LAR that should occur when a higher NAR is achieved by greater investment in photosynthetic machinery, which decreases specific leaf area (Poorter and Remkes 1990). Indeed, LAR depends on the proportion of biomass allocated to leaves relative to the total plant mass and on how much leaf area a plant develops per unit leaf biomass, being LAR = LMR × SLA. No significant difference in SLA and LMR among treatment was observed (Figure 1d,e), but a greater leaf area development for plants grown upon OM fertilization compared to control and DMPP plants was detected (data not shown); from the above consideration, it follows that the highest NAR in OM plots was due to a greater light interception compared to plants grown upon mineral fertilization, that led to a better fresh fruits yield compared to control and DMPP plants (Figure 1f). Thus, organo-mineral fertilization – contrarily to mineral fertilization that provides nutrients to the crops mainly at early vegetative growth stages – acts as a better nutrient source compared to mineral fertilization providing nutrients at the later stages of the crop development, taking some time for mineralization.

Soil N_2O emissions. In control and OM plots, N_2O fluxes measured from chambers positioned along plant rows were higher ($P < 0.01$) than those measured from chambers placed on the bottom of furrows (Figure 2a,c) due to a higher N availability (Figure 3a,c) for biological transformations. The positive correlation ($P < 0.005$) (control: $N_2O\text{-}N = 30.1 + 0.07\ NO_3^-\text{-}N$, $r^2 = 0.308$; OM: $N_2O\text{-}N = 25.0 + 0.39\ NO_3^-\text{-}N$, $r^2 = 0.341$) between N_2O fluxes and soil NO_3^--N concentration, indicates that nitrification was the main biological process involved in

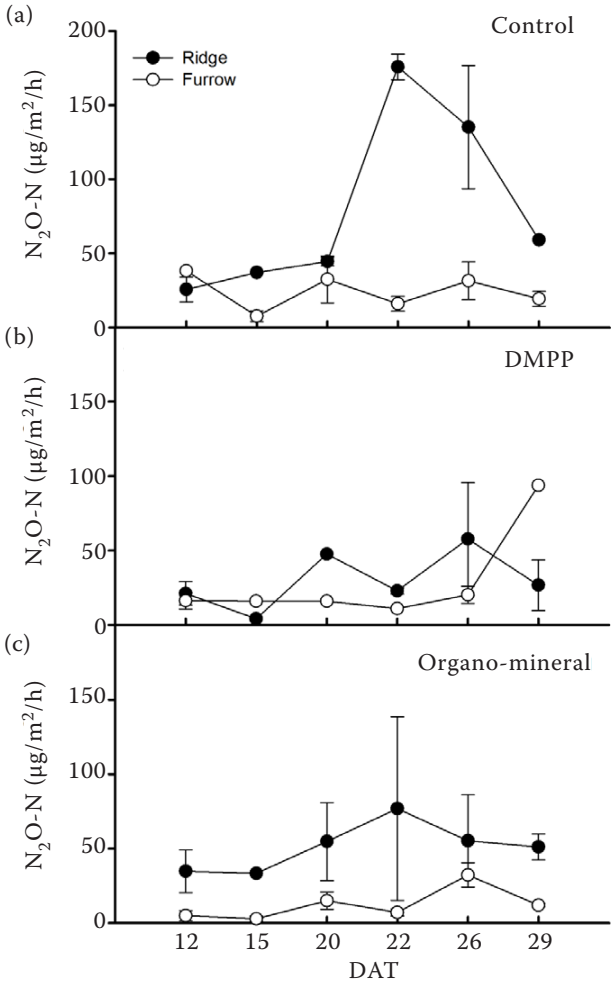

Figure 2. Soil N_2O fluxes measured on ridges and furrows for (a) control; (b) Entec (3,4-dimethylpyrazole phosphate (DMPP)), and (c) organo-mineral plots. DAT – days after transplanting. Data are means '(n = 3) ± standard error

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N_2O production, NO_3^--N being the end product of nitrification. This conclusion is supported also by WFPS values ranging from 40% and 70% (data not shown) that fell in the typical range for nitrification (Huang et al. 2014). In DMPP plots, no significant difference between N_2O fluxes measured from the two positions was found (Figure 2b), although NH_4^+-N content was higher along plant rows than in furrows, and fluxes were the lowest than those measured in control and OM plots. This indicates that under the recorded environmental conditions the 3,4-dimethylpyrazole phosphate (DMPP) was efficient to inhibit the nitrification, thus limiting N losses as N_2O. In fact, soil temperatures remained close to 20°C in all treatments (data not shown) beyond which the 3,4-dimethylpyrazole phosphate degradation is accelerated (Zerulla et al. 2001, Vitale et al. 2013). The effectiveness of DMPP to mitigate N_2O production determined an emission factor (EF1) smaller than 0.2% in both sites (C_{ridge} = 0.45%, C_{furrow} = 0.12%; $DMPP_{ridge}$ = 0.16%, $DMPP_{furrow}$ = 0.12%; OM_{ridge} = 0.26%, OM_{furrow} = 0.07%), comparable to the values reported in others studios (Ranucci et al. 2011, Vitale et al. 2013) and lower that those estimated for mineral and organo-mineral fertilizers, confirming the efficiency of 3,4-dimethylpyrazole phosphate into contrasting NH_4^+-N oxidation also in soils with coarse texture (Vitale et al. 2013).

The EF1 for organo-mineral fertilizer was lower than that for mineral fertilizer (C_{ridge} = 0.45%; C_{furrow} = 0.12%; $DMPP_{ridge}$ = 0.16%; $DMPP_{furrow}$ = 0.12%; OM_{ridge} = 0.26%; OM_{furrow} = 0.07%), in particular for the emissions measured on ridges.

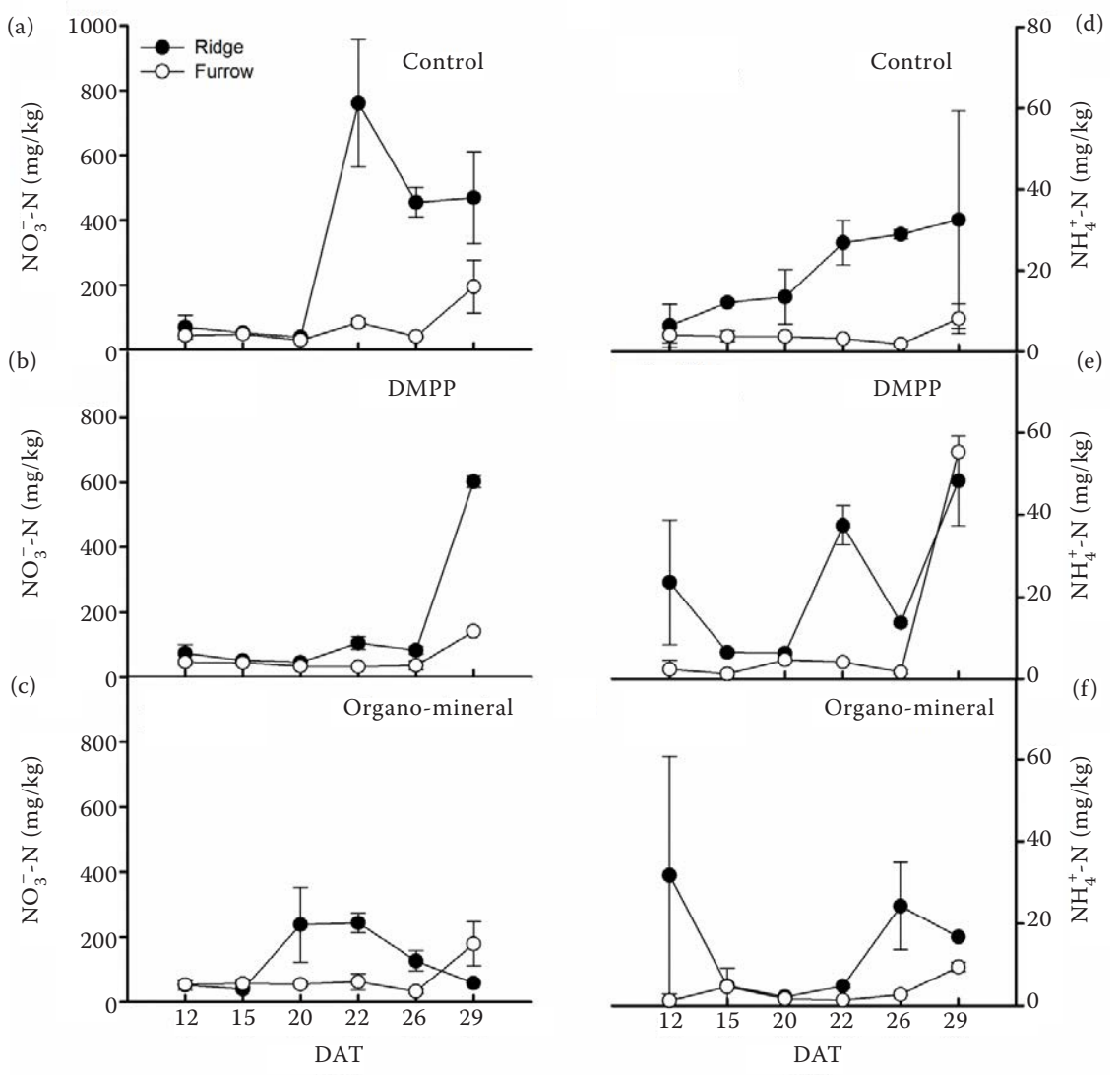

Figure 3. Soil nitrate (a–c) and ammonium (d–f) content in ridges and furrows for control, Entec (3,4-dimethylpyrazole phosphate (DMPP)), and organo-mineral plots. DAT – days after transplanting. Data are means (n = 3) ± standard error

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Our data show that the organo-mineral fertilizers not only improved crop yield compared to mineral fertilizers but also contributed to a reduction in N_2O emission. Some authors (Kaiser and Ruser 2000, Yao et al. 2015) reported higher N_2O fluxes in soil treated with organic and organo-mineral compared to soils treated with mineral fertilizers. Conversely, our data confirm the results obtained by Ball et al. (2004) who measured lower N_2O fluxes from soils treated with organic fertilization using dried pellets compared to the mineral fertilization, due to an enhanced microbial respiration, as a consequence of higher labile carbon content, which limits oxygen availability and favours a complete denitrification to N_2. According to Tiedje et al. (1982), the organic carbon is more important than oxygen in determining denitrification. In our study, soil organic matter content and C/N ratio were low and similar for all treatments over the study period (about 1.4 g/kg and 7.5 g/kg, respectively). Thus, it was stated that the supply of dried organic manure did not increase denitrification, neither lead to an increased respiratory demand for oxygen, causing anaerobic sites and complete denitrification. Otherwise, a negative relationship between N_2O and NO_3^--N content should have occurred if denitrification was the main process producing N_2O. The study hypothesizes that the lower N_2O fluxes in organo-mineral plots compared to mineral plots were due to the reduced C and N availability in the soil, as a consequence of slow mineralization of organic component, and to a better nutrient use efficiency by plants, that limited available N for biological transformations leading to N_2O evolution. It can be concluded that dried organic manure is useful to minimize the risk of large N_2O emissions from agricultural sites.

Acknowledgements

Authors thank K + S Agricoltura S.p.a. (Cesano Modeno MB, Italy) and Dr. Dante Francesco Giovine for the supply of Entec© fertilizer.

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Received on October 18, 2016
Accepted on March 21, 2017
Published online on March 31, 2017