Atmospheric Pollution Research xxx (2017) 1–7

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Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr

Impact of vineyard cover cropping on carbon dioxide and nitrous oxide emissions in Portugal

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A R T I C L E I N F O

Article history:
Received 11 April 2017
Received in revised form 22 June 2017
Accepted 15 July 2017
Available online xxx

Keywords:
Cover cropping
Emission factor
Greenhouse gases
Mediterranean vineyards
Soil tillage

A B S T R A C T

Scarce studies have been published reporting field measurements of nitrous oxide (N_2O) emissions from vineyards, particularly for European conditions. The aim this study was to assess the effect of conventional tillage and no-tillage cover crops on direct N_2O emission factor from vineyards (*Vitis vinifera* L.) in Portugal. A two-year field study was carried out in central Portugal (Nelas, Portugal). The experiment was established in a mature non-irrigated vineyard. The following four treatments with three replications were considered: soil tillage of the inter-row (Till), treatment Till followed by application of mineral fertiliser (50 kg N ha^{-1}) (Till + N), permanent resident vegetation in the inter-row (NoTill), and treatment No-Till followed by application of mineral fertiliser (50 kg N ha^{-1}) (NoTill + N). The carbon dioxide (CO_2) and N_2O fluxes were measured by the closed chamber technique and analyzed by gas chromatography during two consecutive growing seasons (March-September of 2015 and 2016) of the grapevine crop. The results showed that the average direct N_2O EF for vineyards managed with conventional soil tillage in the inter-row was 0.57 ± 0.12% of N input and cover cropping by permanent resident vegetation in the inter-row reduces N_2O emission in 60% (0.23 ± 0.29% of N input). Thus, the vineyard cover cropping was recommended as mitigation measure in order to reduce N_2O emissions. The defaults direct N_2O EF currently recommended by IPCC was not appropriated for vineyards and N_2O emissions are currently potentially overestimated in the Portuguese inventory.

1. Introduction

Nowadays, the viticulture and oenology is a strategic sector for Portuguese economy and accounted 178,957 ha of cropped area and about 700 millions L per year of wine for consumption and exportation in 2015 (INE, 2016). Actually, the agricultural surface area used for grapevine production represents ca. 7% of the agricultural area in Portugal, being the seventh country of the world with higher vineyard area.

Nitrous oxide (N_2O) is a potent greenhouse gas emitted from nitrification, nitrifier-denitrification and denitrification processes, being responsible for the destruction of the ozone layer, increase of global warming and climate change (Sá et al., 2015; Kijewska and Bluszcz, 2016; Kim et al., 2017; Szulejko et al., 2017). Nitrous oxide emissions are always observed after the application of mineral and organic fertilisers into the soils (Chen et al., 2015; Rashti et al., 2015; Fangueiro et al., 2017). The application of mineral fertilisers accounted 35% of the total N_2O emissions from direct agricultural soil emissions reported in the Portuguese inventory in 2014 (PNIR, 2016). The National greenhouse gas emissions inventory (PNIR, 2016) was based on the IPCC recommendations and the default emission factor (EF) currently used by the National inventory for direct N_2O emissions was a generic fertiliser induced EF for agricultural crops (e.g. 1% of N input).

Vineyards are cropped with different soil management practices such as cultivation, intermittent herbicide application and soil

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Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2017.07.006

1309-1042/

tillage, mulching and cover cropping. Besides, several agronomic and environmental advantages have been appointed to vineyard cover cropping such as water management, grapevine performance and soil conservation (Guerra and Steenwerth, 2012; Aguilera et al., 2013; Longbottom and Petrie, 2015; Sanz-Cobena et al., 2017).

To our knowledge, scarce studies have been published reporting field measurements of N_2O emissions from vineyards, particularly for European conditions. Previous studies (Steenwerth and Belina, 2010; Garland et al., 2011; Aguilera et al., 2013; Verhoeven and Six, 2014; Cayuela et al., 2017) reported that cover cropping of vineyards has the potential for reducing N_2O emissions relative to conventional practices, but none of these studies was made direct measurements under the environmental conditions (soil and climate) of Southern Europe. Hence, it could be hypothesised that vineyards managed with cover crops lead to lower N_2O losses than conventional practices. In order to fulfil this gap, the aim this study was to assess the effect of conventional tillage and no-tillage cover crops on direct N_2O emission factor from vineyards (*Vitis vinifera* L.) in Portugal.

2. Material and methods

2.1. Site description

The field experiment was carried out during two consecutive seasons (March to September of 2015 and 2016) at the Dão Wine Research Station (latitude: 40.516667°, longitude: −7.850000°, elevation: 440 m above mean sea level) located in central Portugal (Nelas, Portugal). The vineyard (*Vitis vinifera* L.) was a mature non-irrigated vineyard (*Vitis vinifera* L.), planted in 2000, with the Touriga Nacional red grape variety and grafted onto 110R rootstock. The grapevines were spaced 1.1 m within and 2.0 m between rows (density: 4545 grapevines ha^{-1}, orientation: North - South), trained on a vertical shoot positioning with a pair of movable wires and spur-pruned (12 nodes per grapevine) on a bilateral Royat Cordon system. The agronomic practices used in the field experiment during the two consecutive seasons were similar to those used in commercial vineyards.

The soil of the experimental field was of granite origin and classified as a Dystric Cambisol (WRB, 2015) with a loamy-sand texture (625 g kg^{-1} coarse sand (0.2–2 mm), 175 g kg^{-1} fine sand (0.02–0.2 mm), 170 g kg^{-1} silt (0.002–0.02 mm) and 30 g kg^{-1} clay (<0.002 mm). The physical-chemical properties of the soil plough layer (0–300 mm) were: bulk density: 1.36 g cm^{-3}, pH (H_2O): 5.5, water content at pF 2.0: 175.0 g kg^{-1}, and organic matter: 5.0 g kg^{-1} dry soil.

The study area has a Mediterranean climate with a mean annual air temperature of about 6.9 °C and 21.4 °C in the coldest (January) and in the warmest (July) months, respectively, and a mean annual precipitation of 1170 mm (65% rainfall between October and February).

2.2. Experimental design

The experimental design consisted of four treatments arranged in a randomized complete block design (RCBD) with three replicates. The four treatments considered were:

1. Soil tillage (100 mm depth) of the inter-row (treatment: Till);
2. Soil tillage (100 mm depth) of the inter-row and application of mineral fertiliser (50 kg N ha^{-1}) (treatment: Till + N);
3. Cover crop (permanent resident vegetation) in the inter-row (treatment: NoTill);
4. Cover crop (permanent resident vegetation) in the inter-row and application of mineral fertiliser (50 kg N ha^{-1}) (treatment: NoTill + N).

The experiment was set up in March-2010 and each plot had an area of 19.8 m^2 (9.9 m length × 2.0 m width). The resident vegetation of the field plots was composed by the following order of abundance: *Conyza bonariensis* (L.) Cronq., *Calendula arvensis* L., *Plantago lanceolata* L., *Sonchus oleraceus* L., *Lavatera cretica* L., *Lamium amplexicaule* L., *Erodium moschatum* (L.) L'Hér., *Geranium molle* L., *Raphanus raphanistrum* L., *Chamaemelum fuscatum* (Brot.) Vasc., *Chondrilla juncea* L., *Echium plantagineum* L., *Geranium dissectum* L., *Fumaria officinalis* l., *Rumex conglomeratus* Murray, *Rumex crispus* L., *Rumex pulcher* L., *Ornithopus compressus* L., *Misopates orontium* (L.) Raf., *Vicia sativa* L., *Trifolium repens* L., *Echinochloa crus-galli* L., *Lolium multiflorum* Lam., *Senecio vulgaris* L., and *Sanguisorba minor* Scop. ssp. magnolii(Spach) Briq..

The soil tillage (100 mm depth) and the mowing of resident vegetation were performed twice a year and in the same day (17-March and 12-June 2015 in the first year, and 1-April and 19-June 2016 in the second year). The soil tillage was made with a cultivator mounted on a tractor whereas the resident vegetation was mowed with a brush cutter. The treatments Till + N and NoTill + N received mineral fertiliser, in ammonium sulphate form, at a rate of 50 kg total N ha^{-1} (22-March 2015 in the first year, and 5-April 2016 in the second year). The mineral fertiliser was applied homogenously and immediately incorporated (20 mm depth) by hand in the signed plots.

The grapevine growth cycle begun at the end of March in each year (2015 or 2016) and the harvest was made in 25-September 2015 in the first year and 6-October 2016 in the second year. The weight per grapevine was recorded at harvest in order to assess yields.

A meteorological station (CR800, Campbell Scientific, UK) located in the experimental site was used to collect rainfall and soil temperature (0–200 mm depth) data during the experimental period (Fig. 1A–B).

2.3. Measurement of gas fluxes

The carbon dioxide (CO_2) and N_2O fluxes were measured by the closed chamber technique during the grapevine growth cycle (Pereira et al., 2013; Fangueiro et al., 2017). Measurements were performed daily in the first 7 days after amendment, every three days in the next two weeks and weekly for the rest of the measurement period. Measurements always occurred between 10 h am and 12 h am in each sampling date.

For measuring gas fluxes in the sampling dates, one polyvinyl chloride chamber (L = 200 mm, H = 170 mm), fitted with one septa to allow air sampling, was inserted into the soil (H = 50 mm) of each plot. The chambers were kept in fixed places throughout the season. After closure of the chamber, a first gas sample (25 mL) was immediately taken (time-zero (X_0) sample) using a plastic syringe and flushed through gas vials (20 mL). After 30 min (X_1) and 60 min (X_2) of closure, the headspace of each chamber was sampled again following the same sequential order to ensure that the same time had elapsed between sampling in each chamber. The vials were analysed up to 30 days after sampling. The concentrations of the gas samples stored in vials were measured by gas chromatography using a GC-2014 (Shimadzu, Japan) equipped with a thermal conductivity detector (TCD) for CO_2 and an electron capture ^{63}Ni detector (ECD) for N_2O. The GC-2014 accuracy was 1 ppm to 1% for CO_2 and 50 ppb to 100 ppm for N_2O.

The gas fluxes were determinate using a similar procedure to