EFFECT OF ORGANIC TREATMENTS ON SOIL CARBON AND NITROGEN DYNAMICS IN VINEYARD[(+)]

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Abstract

The work aims to investigate the effects of different soil management strategies on carbon sequestration and total nitrogen in areas of vineyards suffering from loss of soil functionality. Treatments, selected for inter-row management, to re-install soil functionality were based on compost or other organic amendments (COMP), green manure (GM), and dry mulching (DM) strategies using winter legumes and cereals. Cover crops were seeded in fall and mown in late spring, leaved in the ground for mulching in DM or incorporated into the uppermost soil layers in GM. Such approaches were investigated in six vineyards in Italy, six in France, and two vineyards in Slovenia and Turkey. The results showed that COMP significantly increased total organic carbon (TOC) and total nitrogen (N_{tot}) in the topsoil after one year of application. Also DM tends to increase significantly TOC in the topsoil, but only after two years. Modelling 20-year carbon stock dynamics in Italy vineyards, the average increase resulted 0.49, 0.34, 0.21 and 0.03 Mg C ha-1 yr^{-1} for COMP, DM, GM and control, respectively.

Keywords: *carbon stock, climate change, organic agriculture, organic matter, viticulture*

Introduction

Strategies for sequestering carbon in soil not only reduce greenhouse gas emissions, they also enhance soil functionality and biodiversity and improve water regulation and nutrient cycling.

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Soil total organic carbon (TOC) is also a key factor that stabilizes soil aggregates (Martínez-Mena et al., 2012) and increases water infiltration and retention (Rawls et al., 2003).
It is quite common to have scarce TOC in vineyards, particularly in Mediterranean areas, because of several factors. First of all, vineyards are usually situated in hilly areas and on soils that are little fertile and vulnerable to erosion. Moreover, land preparation to adapt vineyards to mechanization is a common practice that, sometimes, create degraded areas because of reduction of soil depth and water storage capacity, too high enrichment of calcium carbonate in the topsoil, losing of soil structure, and reduction of organic matter and nitrogen (N_{tot}), among others (Costantini et al., 2015).
The life cycle assessment (LCA, ISO14044) aims at promoting sustainable agricultural cropping systems and is increasingly applied, however opens new methodology challenges (Notarnicola et al., 2017; Goglio et al., 2017). Accounting for soil carbon changes in LCA (Goglio et al., 2015) allows to better assess carbon footprint and select best practices to increase carbon stock (Cs) in vineyards (Vicente-Vicente et al., 2016).
The aim of this work was to investigate the effects on TOC, N_{tot}, and carbon stock (Cs) dynamic of different soil management strategies in vineyard areas characterized by reduced soil functionality. The trend of TOC and N_{tot} in the topsoil (0-30 cm) was investigated for two years after treatments. TOC and N_{tot} of non-degraded sites within the same vineyards were also monitored.

Materials and methods

Study areas

The vineyards studied were selected from 7 commercial wineries in Italy, France, Slovenia and Turkey. The Italian farms were situated in Chianti Classico wine district (Fontodi farm, Panzano in Chianti village) and in Maremma (San Disdagio farm, Civitella Marittima village), and they were characterized by three vineyards each, cultivated with Sangiovese cultivar. Fontodi farm has been an organic farm since 15 years and the vineyards have permanent grass cover. San Disdagio farm has been organically managed since 2014, just one year before the project starting, and the soil was generally tilled once per year.
The French farms were in Montagne Saint Emillion, Gironde (Maison Blanche winery) and Narbonne, Aude (Pech Redon winery). Both farms have been conducted with organic management since more than 10 years, and the conventional soil management was alternate inter-rows with tillage and natural grass cover. The cultivars of the selected vineyards were Cabernet Franc and Syrah, respectively.
The two Slovenian vineyards belong to a family farm and they are situated in Bonini and Prade village, near Koper. Both vineyards, cultivated with Refosk cultivar, have been organically managed and no tilled since about 20 years. The two Turkish vineyards (Çelebi and Evran farm), cultivated with table grapes (Early Cardinal and Yalova Incisi), were situated in Ceyhan (Adana) and Tarsus (Mersin),

respectively. These vineyards have been organically managed since 2 years before this work, and they are normally tilled once or twice per year. The climate is warm Mediterranean in Italy (precipitation around 750-800 mm/year), Narbonne, France (560 mm/year), and Turkey (precipitation around 600-700 mm/year), whereas is warm and temperate oceanic in Slovenia (precipitation around 940 mm/year) and Gironde, France (950 mm/year), respectively.

The soils of the experimental vineyards were *Cambic Calcisols*, *Haplic Calcisols* and *Calcaric Cambisols* (IUSS Working Group WRB, 2014), with the only exception of Maison Blanche where *Stagnic* and *Haplic Luvisols* were also individuated. The main factors driving soil degradation were the excessive earth movements before plantations, along with excessive water erosion in sloping vineyards.

Organic treatments tested for soil restoring

Each degraded area within the experimental vineyards was subdivided into 4 plots (around 250 m^2 each), where the following restoring strategies were implemented: i) composted organic amendment (COMP; manure and/or pruning residue, applied in November 2015 and 2016); ii) green manure (GM) with winter legumes and cereals, incorporated into the soil in May-June 2016 and 2017; iii) dry mulching (DM) by legumes, mown and left on the soil surface in May-June 2016 and 2017; iv) tillage with no fertilization, used as control treatment (CONTR). In addition, a representative plot of non-degraded areas within each vineyard (ND) was selected, in order to monitor the trend of TOC and N_{tot} in vineyard standard state. Each ND plot was kept under the ordinary vineyard management used in the Farm, consisting of natural grass covering in Italy, France and Slovenia, and tillage (performed once or twice a year) in Turkey. More details regarding study areas were shown in D'Avino et al. (this issue).

The cover crops used for GM and DM treatments did not achieve good growth and soil cover in Fontodi (Italy), Pech Redon (France), Bonini and Prade (Slovenia) during the winters 2015-2016 and 2016-2017, especially in the latter, which was particularly dry. In these cases the vineyards had high stoniness (30-40%) or too low fertility (Pech Redon), which caused non-optimal conditions for cover crop seeding and germination.

Organic carbon and nitrogen monitoring

Soil sampling for total organic carbon (TOC) and total nitrogen (TN) monitoring was carried out on April 2015 (time zero), 2016 and 2017, immediately before the execution of the experimental treatments (cover crop mowing, incorporation of green manure). The sample size was the same for all the treatments (n=20) in 2016 and 2017, whereas in 2015 the sample size of degraded area was higher (n=80) than that of non degraded areas (n=20).

Each plot within degraded and non-degraded areas was sampled by auger in three selected points, at depth increments of 0-10 and 10-30 cm. The cores from the three sampling points were mixed thoroughly to provide a single composite sample per

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layer per plot. The samples were air-dried at room temperature and sieved through a 2 mm mesh. A representative amount from each bulk sample was ground to < 0.5 mm and used for the analysis. TOC and N_{tot} contents were assessed by dry combustion, with a Thermo Flash 2000 CN elemental analyzer. The TOC analysis was performed on 20 to 40 mg soil sub-samples weighed into Ag-foil capsules and pre-treated by 10% HCl until complete removal of the mineral carbon resulting from carbonates. The N_{tot} content was assessed separately on untreated sub-samples.

The relative variation (ΔX) in TOC and N_{tot} between 2015 and 2016, and between 2015 and 2017 for each plot was calculated as follow:

$$\Delta X_{(T,2015)} = \left[\frac{X_{(treat.T)} - X_{(treat,2015)}}{X_{(treat,2015)}} \right] \cdot 100 \qquad [1]$$

Where X is TOC or N_{tot}, *treat* is the treatment (COMP, DM, GM, CONTR, or ND) and T is the year (2016 or 2017). TOC and Ntot relative variations under the different treatments were compared with those in the control areas (CONTR and ND) by ANOVA. We used relative increasing in each plot instead of absolute values because of the different baseline of TOC and N_{tot} in the studied vineyards.

Carbon stock

A descriptive model (D'Avino et al 2017; Razza et al 2018) based on Henin-Dupuis methodology (Fernandez-Tirado 2013), already widely applied in cropping systems assessment (Saffih-Hdadi and Mary, 2008) was used to assess carbon stock (Cs) dynamics under the different treatments in the two outlined Italian farms. Cs was calculated following formula reported by Fantappiè et al. (2010). According to IPCC (2006) methodology, Cs was assessed only in the topsoil (0-30 cm), this being the soil layer most affected by management. In order to evaluate soil potential mineralization before treatment, mean annual temperature, total organic carbon, coarse material, bulk density, clay and carbonates contents were taken into account for each of the 24 sample points (3 plots x 4 treatments x 2 farms). In order to model Cs dynamics, frequency and deep of tillage, amount, type and frequency of organic applications, amount and type of epigeal and hypogeal interrow biomass were considered in each of the four treatments, during 3-year trials. Regarding vine residues, fallen leaves were estimated to be 945 kg/ha dry matter per year as reported in Italy for the Guyot training system (Fregoni, 1980), while pruning residues were not considered as they were removed in both farms. The isohumic coefficient adopted for this work is not affected by soil type (Noirot-Cosson et al., 2017), and is 0.23 for compost dry matter following measured ash content and Houot et al. (2005). Regarding inter-row total biomasses, the isohumic coefficients adopted were 0.12, 0.11 and 0.10 for DM, GM, and COMP and CONTR, respectively, in relation to the different cereal-legumes composition as reported by Boiffin et al. (1986) and Tremblay et al. (2010). The model sets a three year cropping system (from April 2015 to April 2018), with soil treatments

applied in first two years and no treatments in the third year. The model reiterated this cycle to reach 20 years, the minimum period indicated by the IPCC (2006) to reach soil equilibrium.
The Cs increasing assessed by the model were compared with increment required by soil carbon 4 per mille initiative by the formula:

$$Cs_n = Cs_0 \times \left[1 + \frac{1}{1000} \right]^n \qquad [2]$$

where Cs_0 is the carbon stock at the baseline that increases (+) after n years to reach the Cs_n by a certain increment (I). In the "4 per mille initiative" I=4, in this work n=20.

Results and discussion

Effects of the treatments on organic carbon and nitrogen

The TOC and N_{tot} contents of the topsoil (0-30 cm) at the beginning of the trial (before the start of organic treatments) showed significant differences between degraded and non-degraded areas (Fig.1). This confirms TOC and N_{tot} as good indicators of soil degradation, despite the high variability of soil characteristics. On average, TOC concentration was 6.7±2.4 $g \cdot kg^{-1}$ in degraded areas, and 10.0±4.3 $g \cdot kg^{-1}$ in non-degraded areas. N_{tot} behaved similarly, averaging 0.85±0.38 $g \cdot kg^{-1}$ and 1.14±0.43 $g \cdot kg^{-1}$ in degraded and non-degraded areas, respectively.
After one year of treatment (Fig. 2, left), there was a significant relative increase in TOC content only under COMP compared to CONTR (+56%). On average, TOC increased also under GM and DM, however the increases did not differ statistically from those under CONTR and ND. On the other hand, no significant differences between treatments were observed for N_{tot}.
After two years of treatments (2017, Fig. 2, right), there was still a relative increase in both TOC and N_{tot} under COMP (+47.5% and +93%, respectively), which was significantly greater than under CONTR (+12.6% and 55.6%, respectively). Although also in DM the relative increase of TOC and N_{tot} was higher (+39.1 and + 60.3%, respectively) than in CONTR, the difference was not statistically significant because of a high standard deviation.
On average, after two years of treatments, the topsoil TOC content under COMP was 10.0±4.9 $g \cdot kg^{-1}$, very close to that of non-degraded area (ND: 10.5±6.8 $g \cdot kg^{-1}$). In both cases, TOC values were significantly different from those under DM, GM, and CONTR, which averaged 8.4±3.3 $g \cdot kg^{-1}$, 7.6±3.5 $g \cdot kg^{-1}$, and 7.4±3.4 $g \cdot kg^{-1}$, respectively. The same trend was showed by N_{tot}.
Based on our results, GM was the only treatments that did not increase TOC and N_{tot}, as compared to CONTR. Probably, this was due to: i) poor and uneven growth of cover crops in several vineyards, especially during 2017; ii) a possible effect of tillage carried out to incorporate green manure in late spring, which combined with the increasing temperature may have accelerated soil organic matter mineralization.

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On the contrary, TOC increased under DM, even if the cover crops experienced similar germination and growth problems as under GM, and despite some plots had scarce vegetation cover. In this regards it must be considered that in DM no tillage was performed during the experimental years and grass mowing was the only operation carried out. This management may have resulted in less soil disturbance and better stabilization of soil organic matter, thus increasing the potential for OC sequestration.
It is important to remark that, on average, COMP treatments increased TOC more than ND already after the first year of treatment, while under DM TOC increase became significantly higher than in ND after two years of treatments.

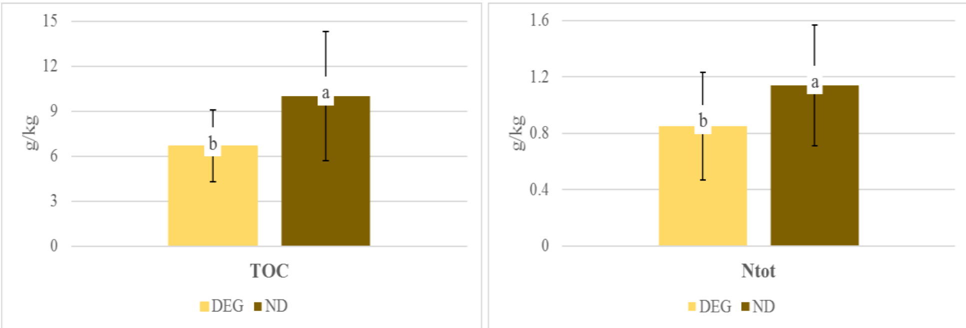

Figure 1. *Total organic carbon (TOC), total nitrogen (N_{tot}), in degraded (n=80) and non-degraded (n=20) areas in the experimental vineyards, before the implementation of organic treatments. Letters a and b show the significant homogeneous groups (p<0.05) after Student's T-test.*

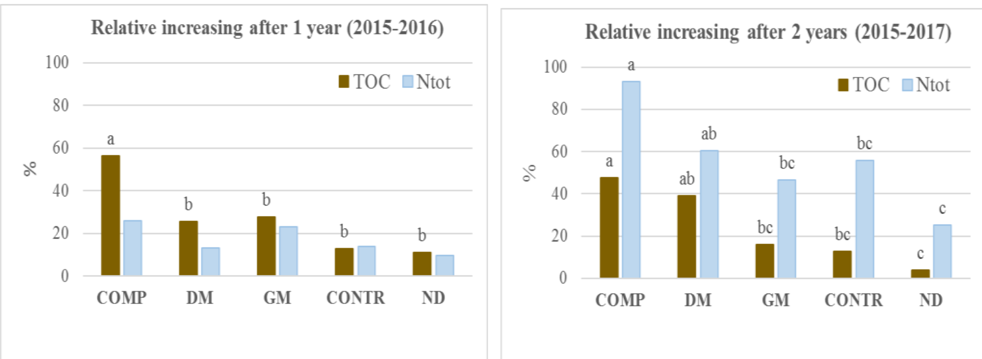

Figure 2. *Relative increasing (%) of TOC and N_{tot} in the different treatments (n=20) after one (on the left) and two years (on the right) of treatments. The letters individuate homogeneous groups according to Fisher's LSD test (p < 0.05).*

Carbon stock dynamics

The average topsoil Cs observed before starting treatments (2015) in the two farms was about 20 t/ha, with a variation coefficient greater than 30%. The results provided for each treatment by the model for 2016 and 2017 were in the range of the measured mean values ± standard deviation, however the high Cs variations and the short terms of observation did not allow the validation of the model in vineyards.

As shown in Figure 3, CONTR did not increase soil TOC stock, unlike all other treatments, which instead reached the theoretical 4 per 1000 Cs increase proposed at COP21 as a compensation for the global emissions of greenhouse gases by anthropogenic sources (Minasny et al., 2017). After 20 years, the Cs_0 increase was estimated at 22, 17, 22 and 2‰ for COMP, DM, GM and CONTR, respectively, corresponding to 0.49, 0.34, 0.21 and 0.03 Mg C ha^{-1} yr^{-1}. The relative increase in Cs resulted equal to 0.49, 0.34, 0.21 and 0.03 Mg C ha^{-1} yr^{-1} for COMP, DM, GM and CONTR, respectively. Our results were in line with 0.2-0.5 Mg C ha^{-1} yr^{-1} worldwide Cs accumulation rates of agricultural land after the adoption of best management practices as suggested by Minasny et al. (2017), and with carbon sequestration reported for cover crop by Poeplau and Don (2015).

In agreement with findings reported by Vicente-Vicente et al. (2016) for Mediterranean vineyards, the relative Cs increase was higher under compost than under cover crop treatment. DM increased Cs more than GM, because of less soil disturbance by tillage, allowed by the self-seeding of clover in autumn and no incorporation of residues in late springtime. The COMP treatment provided 2 t/ha/y of average dry matter compost, which allowed to increase soil organic matter more than other treatments, also as a result of the greater biomass production across the inter-rows, and despite the higher estimated Cs mineralization associated to higher frequency of tillage and organic matter application.

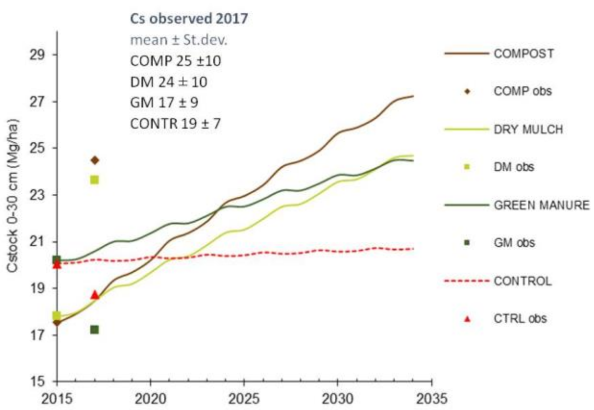

Figure 3
Carbon stock (Cs) dynamic for plots with different inter-row management. Average data observed in two organic Italian wineries, modelling until 20 years by 3-y trial observation.

Conclusions

The use of compost-based organic amendments (COMP) was the most effective treatment to improve soil total organic carbon (TOC) and nitrogen (N_{tot})

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enrichment in the degraded vineyards soils. On average, this treatment resulted in TOC and N_{tot} amounts comparable with those of the topsoil of non-degraded areas (0-30 cm) after 2 years. The restoring performance of cover crops appeared to be strongly site- and weather-dependent, with uneven results across the investigated areas. In particular, the stony soils, characterized by very low fertility, showed problems in seed germination and cover crops growing, which made these treatments rather useless in the considered areas. Cover crops used for dry mulching (DM) seemed to increase organic carbon more than green manure, probably because of the mulch effect and less soil disturbance before summer.
It should be emphasized that, according to the site-specific model adopted, the vineyard management systems selected, if repeated for two years and then suspended for one, are expected to increase the topsoil Cs over a 20 years period by more than 0.4%, thus satisfying the OC increase agreed by the “4 per mille soils for Food Security and Climate” initiative (Minasny et al, 2017).

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