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Soil profile dismantlement by land levelling and deep tillage damages soil functioning but not quality

Vito Armando Laudicina[a], Eristanna Palazzolo[a], Anna Piotrowska-Długosz[b], Luigi Badalucco[a,*]

[a] Dipartimento Scienze Agrarie e Forestali, Università degli Studi di Palermo Viale delle Scienze, Edificio 4, 90128 Palermo, Italy
[b] Department of Soil Science and Soil Protection, Division of Biochemistry, Faculty of Agriculture and Biotechnology, UTP University of Science and Technology, 6 Bernardyńska St., 85-029 Bydgoszcz, Poland

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ABSTRACT

We investigated the effects of land levelling followed by deep tillage, thus inducing a drastic dismantlement of soil profile, on both soil functioning and quality by monitoring various bioindicators (microbial biomass and community structure, basal respiration, enzyme activities) expressed on either whole soil and TOC mass units, respectively. As expected, in disturbed soils all measured properties had much higher coefficients of variation (CVs), regardless of either whole soil or TOC mass basis, due to the induced spatial variability. The amount of total organic C in the first cubic meter of soil profile was of one order of magnitude greater in undisturbed soils compared to disturbed ones. Soil bioindicators monitored on whole soil mass basis appeared greatly worsened while unchanged or even improved under TOC mass basis. This was essentially due to a couple of reasons: (1) soil bioindicators are constitutively dependent on soil TOC content; (2) soil spatial rearrangement may have made some organic C available to microbial biomass, otherwise unreachable when allocated throughout the undisturbed soil profile. Concluding, our work highlighted the need of expressing soil biondicators on soil mass basis when the response of the whole agrosystem to soil deep spatial rearrangement has to be assessed, while on TOC mass basis if the soil biological features are the major concerns.

1. Introduction

A better understanding of the environmental impact by anthropogenic disturbances on soil ecosystem functioning is required to optimize strategies for soil use change, conservation and remediation. During last decades, semi-arid Mediterranean basin has been greatly transformed for land-use change to viticulture (Zdruli et al., 2014).

Deep tillage, besides being usually used for weed control, seed bank preparation and topsoil aeration, may concur for Anthrosols establishment (Dazzi and Monteleone, 2007). It affects the chemico-physical properties of soils and, in turn, the habitat for soil microbial community and the distribution pattern of soil nutrients also along the soil profile (Laudicina et al., 2012; Sun et al., 2011). Besides deep tillage, also land levelling is often carried out to favour a uniform slope gradient and thus facilitate agricultural practices such as irrigation, shallow tillage and other mechanical operations (Martínez-Casasnovas and Ramos, 2009). When land levelling is combined with deep tillage (80–100 cm depth), even soil properties usually thought unmodifiable, such as texture, can change. Such drastic human activities reset the actions of soil forming factors and tend to bring soils back to time zero (Entisolization), thus deeply impacting soil nutrients pools and microbial community structure. Land levelling is currently used in the European agriculture (Cots-Folch et al., 2009; Martínez-Casasnovas and Ramos 2009), but very few studies have been carried out with the aim to investigate induced changes in chemical (Brye et al., 2004; Zdruli et al., 2014) and biochemical soil properties (Brye 2006).

Experimental evidence suggests that the delivery of fresh plant-derived carbon to the subsoil stimulates microbial activity and results in mineralization of thousand-year-old carbon (Fontaine et al., 2007). As a consequence, management practices that increase the distribution of fresh carbon along the soil profile (such as deep ploughing and the use of drought-resistant crops with extensive root systems) may stimulate loss of this ancient buried carbon (Fontaine et al., 2007).

* Corresponding author.
E-mail address: luigi.badalucco@unipa.it (L. Badalucco).

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Microorganisms are the main drivers of soil organic matter dynamics, and it is well known that the whole microbial biomass, as well as its structure, is very sensitive to soil agricultural practices (Laudicina et al., 2011b). Ernst and Emmerling (2009), comparing five tillage systems over a ten-year period, found less invasive tillage systems, such as harrowing, having positive impact on the population size, biomass, and species richness of earthworms, unlike deep ploughing.

Brye et al. (2004) found that changes in soil chemical properties following the land levelling induced a decrease in fungal biomass while bacterial biomass did not change.

Although soil enzymatic activities have been rarely investigated in the vineyard disturbed soils (Miguéns et al., 2007; Peregrina et al., 2014), they can sharply decrease, even up to 90%, compared to undistrurbed ones, but essentially due to a comparable decrease in soil organic C (Miguéns et al., 2007). It is commonly accepted that the enzyme activities are potentially useful for detecting changes in soil quality, since they take part in nutrient cycling and soil functioning as indicators of altered microbial community caused by the environmental impact due to various management practices (Nannipieri et al., 1990).

In soil science it is very common to express any type of variable (physico-chemical, biological, etc.) per soil mass unit. This is obvious for those variables, such as the cation exchange capacity, linked mostly to the largest soil component, i.e. the mineral one. However, the same often occurs also for most of the so-called soil quality and health bioindicators, which govern soil biological processes. although they are constitutively directly correlated to the soil organic matter content (Bastida et al., 2008). When the response of an agro-ecosystem to drastic anthropic action has to be studied, i.e. often in the presence of dramatic TOC declines, it is still reasonable that changes in soil quality parameters, in order to maintain their functional meaning, are measured in terms of whole soil mass rather than TOC mass basis. Generally, the strong reduction in the organic matter content as a result of soil use makes comparison of the absolute values of the different enzyme activities difficult and does not allow a clear diagnosis of the effect of soil use on soil quality, as it is not possible to determine whether the observed modifications in the enzymatic activities are due to the lower content of organic matter in the soils or to real differences in enzymatic activity. One way of overcoming this difficulty and allowing comparison of soils under different types of use is to use the values of specific activity, i.e., the values of activity per unit of carbon (Trasar-Cepeda et al., 2008). The use of this relationship reveals that in the soils affected by anthropic activity the values of specific enzyme activities are generally higher than those in the climax soils. This since land use causes a relevant loss of organic matter (probably the most labile and less stabilized organic matter), with either a smaller decrease or an increase in the absolute enzyme activity, so that the greater the loss of organic matter caused by the intensity of soil management, the greater the enzymatic activity per unit of C. Nevertheless, beyond the specific enzyme activity (Raiesi and Beheshti 2014), another soil quality parameter based on TOC mass, i.e. the microbial quotient, since decades has been widely accepted (Kaschuk et al., 2010). It is directly related to the assimilation efficiency of organic C substrates by microbes (Anderson and Domsch, 1989).

The aims of this study were: (i) to investigate the effects of land levelling followed by deep tillage (herein referred to anthropic disturbance), thus inducing a drastic dismantlement of soil profile with vertical spatial soil mixing, on the redistribution of various C and N pools; (ii) to assess the impact of that disturbance on the relationships between chemical soil properties and microbial biomass, activities and community structure, but with soil bioindicators expressed on either whole soil mass, thus giving an estimate of the rate at which nutrients were made actually available to microorganisms and plants (soil functioning) and TOC mass units, thus giving an estimate of how suitable was the organic matter to sustain biological processes (soil quality). We hypothesized that such drastic anthropic disturbance for implanting vineyard homogenized the soil chemical and physical properties along the profile, thus (i) reducing the organic C and N total pools on whole soil mass basis, i.e. soil functioning, but (ii) not necessarily worsening the soil quality.

2. Materials and methods

2.1. Study area and soil sampling

The study area is located within the urban limits of Mazzarrone, province of Catania, in the South-East of Sicily, Italy (37.0849°N, 14.5590°E). In the late 1970's vineyards penetrated copiously in the area and produced a large increase in capital income. At present, most of the farms in the area are vine growing, favoured by both climate and pedological characteristics. The average monthly temperature reaches (observations from 1980 to 2000) a maximum of 25.5 °C in August and a minimum of 10.3 °C in January, with an average annual rainfall of 452 mm, thus the area is characterized by Mediterranean climate.

Soil samples were taken in two neighbouring fields located on the North-East of Mazzarrone. The first field (500 × 40 m) had never been cultivated—the old carob and olive trees within it dated back over 100 years (determined by the incremental borer of Pressler). The second field (500 × 80 m), before being converted to vineyards in the 80's, showed the same soils as the uncultivated neighbouring field. The first intervention for planting a trellis system vineyard was carried out in the wider field in 1982. Trenches of about 80–100 cm deep were made with a mouldboarded one-furrow plough, which gave complete overturning and deep stirring up of the horizons. In autumn 2002, after 20 years of intensive cultivation, the vineyards were explanted. In late spring 2003 the morphology of the field, with an undulating morphology and variable slope ranging from 3 to 8%, was gently reshaped, so that soils at more linear morphology were randomly covered with topsoils and subsoils coming from soils at more irregular morphology (up to 50–70 cm layer of marly limestone). In August of the same year the soil was again ploughed up to 80–100 cm with a mouldboarded one-furrow plough. In winter–spring 2003/2004 the soil was destined to durum wheat. In July 2004, i.e. after wheat harvest, nine pedons were opened and described inside the cultivated and reshaped field, while four ones, as control, were opened and described inside the never cultivated field. The four undisturbed soil pedons were sampled according to the sequence of their genetic horizons, whereas the nine disturbed soils pedons were sampled at each 20 cm layer from the soil surface to a depth of 120 cm as no sequence of genetic horizon was still evident. Layers of 20 cm were chosen as it is common in such area to till the topsoil during the vineyard cultivation at such depth. Three soil samples per genetic horizon or layer were collected and analysed separately for chemical and biochemical properties. Soil samples were air-dried and 2 mm sieved prior to laboratory analyses. Reported data were expressed on an oven-dry basis (105 °C). Further details on the study area such as geological settings and profile descriptions are reported in Dazzi and Monteleone (2007).

2.2. Soil chemical analyses

Bulk density was determined according to Blake and Hartge (1986) from undisturbed samples taken using a steel cylinder of 100 cm^3 volume (5 cm in diameter, and 5 cm in height).