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Influence of land use on soil quality and stratification ratios under agro-silvo-pastoral Mediterranean management systems

Rosa Francaviglia[a,*], Anna Benedetti[a], Luca Doro[b], Salvatore Madrau[c], Luigi Ledda[b]

[a] Consiglio per la Ricerca e la sperimentazione in Agricoltura, Centro di ricerca per lo studio delle relazioni tra pianta e suolo, Via della Navicella 2-4, 00184 Rome, Italy
[b] Dipartimento di Agraria, Sezione di Agronomia, Coltivazioni erbacee e Genetica, Università di Sassari, Viale Italia 39, 07100 Sassari, Italy
[c] Dipartimento di Agraria, Sezione di Ingegneria del Territorio, Università di Sassari, Viale Italia 39, 07100 Sassari, Italy

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ABSTRACT

A case study from north-eastern Sardinia (Italy) in semiarid conditions is presented. Agriculture is mainly extensive and markedly agro-silvo-pastoral, and is typical of similar areas of the Mediterranean basin. The following land uses at different levels of crop intensification were considered: tilled vineyard (TV), no-tilled grassed vineyard (GV), hay crop and pasture with sparse cork oaks (HC and PA), semi-natural systems (SN, former vineyards set-aside about 30 years ago), cork oak forest (*Quercus suber* L.) established in the past century (CO). Some soil quality parameters were considered: soil organic carbon (SOC) and total N (TN) concentrations, stocks and their stratification ratios with depth (SRs), microbial biomass carbon (MBC) and its quotient to SOC (*q*mic), and C:N ratios.

Both in terms of concentrations and stocks, SOC and TN were generally higher in HC, PA, CO and SN: in these land uses SOC in the topsoil were in the range 17.0–24.3 g kg^{-1} and 48.9–65.4 t ha^{-1}; TN values were 1.07–2.08 g kg^{-1} and 3.1–6.0 t ha^{-1}.

SOC and TN SRs under the CO land use were higher than 4, quite above the proposed threshold ($\gg$2), >2 in GV, and $\geq$2.0 in PA.

MBC in mg kg^{-1} and *q*mic in μg g^{-1} were higher under CO (194 and 0.89) and GV (156 and 0.97).

C:N ratios had optimum or nearly optimum (9–12) values in CO, PA and the GV, in agreement with the SRs, MBC and *q*mic. A positive and significant correlation was found between SOC and TN concentrations in all the land uses.

1. Introduction

Soil organic carbon (SOC) is a major component of the soil organic fraction, positively affects many soil properties and, consequently, soil functions. In particular, SOC maintains important soil functions with regard to habitat, biological diversity, soil fertility, crop production potential, erosion control, water retention, substance exchange between soil, atmosphere and water, and the filtering, buffering and transforming capacity (Huber et al., 2001; Kirchmann and Andersson, 2001).

C sequestration via agricultural soils has a potential to significantly contribute to climate change mitigation. Sound cropland management can play a positive role in reducing GHGs emissions, and carbon dioxide in particular, through a decrease of soil organic carbon losses, by increasing the organic matter input or combining these two options. Literature data estimate about 1550 Pg SOC to 1 m depth (Lal, 2008), in comparison with 4000 Gg C of fossil fuels. Vegetation (560 Pg) and atmosphere (760 Pg) store considerably less C than soils.

When using SOC to compare "soil quality", we should consider that SOC varies among environments and management systems, and generally increases with higher mean annual precipitation, with lower mean annual temperature, with higher clay content, with an intermediate grazing intensity, with higher crop residue inputs and cropping intensity, with native vegetation compared with cultivated management, with conservation tillage compared with plough tillage (Jenny, 1980; Nichols, 1984; Parton et al., 1987; Burke et al., 1989; Rasmussen and Collins, 1991; Franzluebbers et al., 1998; Schnabel et al., 2001). Since stratification of SOC pools is common both in natural and agricultural cropping systems, Franzluebbers (2002) developed the concept of using a stratification ratio as an indicator of dynamic soil quality, to test the capability of different soil properties to express the extent of stratification, and illustrate the potential of SOC and other soil properties to detect management-induced changes in dynamic soil quality. Stratification ratios >2 indicate a higher soil quality and

* Corresponding author. Tel.: +39 06 7005299; fax: +39 06 7005711.
E-mail address: rosa.francaviglia@entecra.it (R. Francaviglia).

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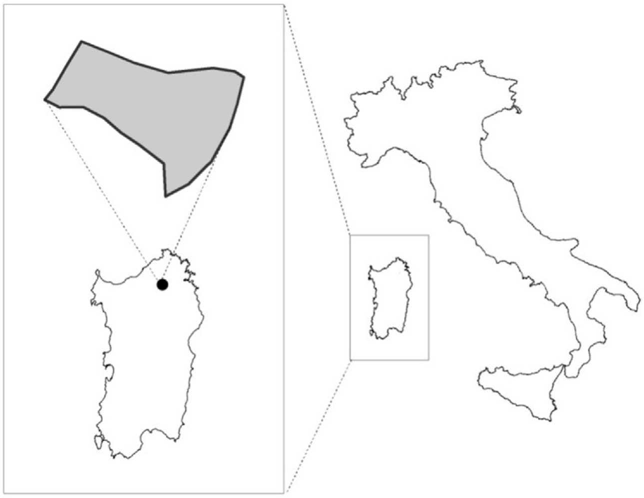

Fig. 1. Experimental site location in northeast Sardinia (Italy).

contribution to agriculture sustainability. Total soil N (TN) is associated with SOC and plays a key role in building soil fertility and enhancing soil productivity (Franzluebbers and Stuedemann, 2008).

Researches under Mediterranean conditions are in agreement with this theory, but available literature mostly deals with intensive agricultural systems and soil tillage practices, and very few studies have addressed only partially the agro-silvo-pastoral Mediterranean management systems (Murillo et al., 2004; Moreno et al., 2006; Hernanz et al., 2009; Peregrina et al., 2010; Nieto et al., 2011; Melero et al., 2012; Corral-Fernández et al., 2013; Lozano-García and Parras-Alcántara, 2013). The aim of this study was to evaluate some soil quality parameters and stratification ratios in land uses at different levels of crop intensification, under agro-silvo-pastoral Mediterranean management systems in semiarid conditions (northeastern Sardinia, Italy). Data are discussed in terms of SOC and TN concentrations and stocks, stratification ratios (SR) calculated from contents in the 0–20 cm soil layer divided by that in the 20–50 cm, microbial biomass carbon (MBC) and its quotient to SOC (*q*mic), and C:N ratios.

2. Materials and methods

2.1. Site description

The site (Fig. 1) is within an area of about 1450 ha in the Berchidda Municipality (40°46′ N, 9°10′ E, mean altitude 285 m a.s.l.), characterized by extensive agro-silvo-pastoral systems, typical of north-eastern Sardinia (Italy) and similar areas of the Mediterranean basin (e.g. the Iberian peninsula). The area is characterized by the same type of soil and cork oak forest (*Quercus suber* L.) as potential native vegetation which has been converted to managed land with pastures and vineyards in recent years (Lagomarsino et al., 2011; Francaviglia et al., 2012). Six land uses, with different levels of cropping intensification were compared (Table 1, Fig. 2):

- Tilled vineyards (TV);
- No-tilled grassed vineyards (GV);
- Hay crop (HC);
- Pasture (PA);
- Cork oak forest (CO);
- Semi-natural systems (SN).

Table 1
Land uses description and management.

Land use	Description
Tilled vineyard (TV)	TV was established in 1993, is ploughed to 40 cm and harrowed in March or April and occasionally in July. Organic fertilization (12.5% organic nitrogen, 40% organic carbon, 70% organic matter and C/N ratio 3.2) is distributed at the end of January at the rate of 500 kg ha^{-1} and incorporated in the first 20 cm of soil with a rototiller; it provides 200 kg ha^{-1} of organic carbon, 62.5 of N, 42 of K and 11 of P. Pruning residues are removed from the field. The monitoring area is 0.98 ha.
No-tilled grassed vineyard (GV)	GV was established in 1990. Mineral fertilizer up to 40 kg N ha^{-1}, 22 kg P and 42 K are applied in March. Pruning is carried out in January and June with the pruning residues being left on the soil. Drip irrigation (up to 100 mm) is provided between June and July to partially restore crop evapotranspiration. The monitoring area is 3.4 ha.
Hay crop (HC)	The HC land use is oats, Italian ryegrass and annual clovers or vetch for 5 years and intercropped by spontaneous herbaceous vegetation in the sixth year. It is ploughed to 40 cm and harrowed before seeding 5 years out of six. 50 kg N ha^{-1} and 39 kg P ha^{-1} are applied before seeding and grazing is allowed with 3–4 sheep ha^{-1} from January until March, before being cut in May. The monitoring area is 3.5 ha.
Pasture (PA)	The PA land use is 5 years of spontaneous herbaceous vegetation, and one year of intercropping with oats, Italian ryegrass and annual clovers or vetch cultivated as a hay crop. It is tilled 1 year out of 6 and is grazed from December until June with 6 sheep ha^{-1}. The HC and PA land uses have a complementary 6-year rotation. The monitoring area is 11 ha.
Cork oak forest (CO)	The CO land use (*Quercus suber* L.) was established in the past century, is used for cork production and cattle grazing and the understory is covered by mixed herbaceous vegetation. The monitoring area is 10 ha.
Semi-natural systems (SN)	The SN land use (scrublands, Mediterranean maquis and Helichrysum meadows) arise from the natural re-vegetation of former vineyards established between 1943 and 1951, which have been set-aside about 30 years ago probably due to the low grape yields and the high cost of modern tillage equipment. The monitoring area is 4 ha.

TV and GV vineyards are agricultural higher intensive land uses, whereas HC, PA, CO and SN are agro-silvo-pastoral lower intensive land uses.

Both PA and HC included scattered cork-oak trees, which are key components of the “Dehesa”-type landscape (grazing system with *Quercus* L.) typical of this area of Sardinia and other areas of southern Europe (e.g. Spain and Portugal). Dehesas are often converted to more profitable land uses such as vineyards (Francaviglia et al., 2012) or olive groves (Lozano-García and Parras-Alcántara, 2013).

The local climate is typically Pluvi-seasonal oceanic low meso-Mediterranean low sub-humid (Rivas-Martinez and Rivas-Saenz, 2009), with a mean annual rainfall of 623 mm (range 367–811 mm) and mean annual temperature of 15.0 °C (13.8–16.4 °C). According to the updated Köppen-Geiger climate classification (Kottek et al., 2006) the climate is warm temperate with dry and hot summers (Csa).