Applied Soil Ecology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Short communication

Soil and ecosystem services: Current knowledge and evidences from Italian case studies

Ferrarini Andrea[a,*], Claudio Bini[b], Stefano Amaducci[a]

[a] Department of Sustainable Crop Production, Università Cattolica del Sacro Cuore, Via Emilia Parmense 84, Piacenza 29122, Italy
[b] Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University, Venice, Italy

ARTICLE INFO

Keywords:
Soil management
Ecosystem services
Soil biota
Ecological intensification
Soil health
Bioenergy crops

ABSTRACT

Soil management is fundamental to all agroecosystems and affects ecosystem processes that are involved in the provision of multiple ecosystem services (ES). Agricultural soils are the habitat for key functional organisms which collectively as soil biota contribute to soil ES provision: supporting biomass production and nutrient cycling, regulating of climate, water and biological control of pests and diseases. As result of an increased awareness on the importance of soil ES, soil science is playing an active role in informing the ecological intensification of agriculture. In this study, the lessons learned from Italian case studies on the usefulness of using a soil health assessment framework based on multiple soil ES are presented. Soil health as an integrative property of agroecosystem management can be evaluated with a set of physical, chemical, and biological indicators representative of essential soil ES. This is the basis of the Soil Management Assessment Framework (SMAF) (Andrews et al., 2004) and it is based on a three-step process that includes indicator selection, indicator interpretation, and integration into a final index. In northern Italy, several field trials have been set up to assess multiple ES provision from bioenergy crops cultivated on marginal conditions and from contrasting vegetable cropping systems. These studies revealed how the use of a comprehensive soil health assessment framework can help: (1) to identify the best soil management practices that deliver multiple ES and (2) to support resource-efficient production. Beyond academic research, the integration of multiple indicators of soil health within the assessment of agroecosystems sustainability is essential if we want to promote ecological intensification of food and bioenergy production.

1. Current knowledge on ecosystem services provided by soil

An ecosystem service is a benefit to society derived from a healthy ecosystem property or process (MEA, 2005). Agriculture occupies a substantial proportion of the European land, and consequently agroecosystems play an important role in maintaining ecosystem services (ES) (Schröter et al., 2005). In the last decade, the ES topic is largely determining the debate in the area of sustainable agriculture (Carpenter et al., 2009). Unsustainable farming practices have an adverse impact on aboveground (Phalan et al., 2011) and belowground biodiversity (Tsiafouli et al., 2015). The increases in yields have relied heavily on intensive use of fertilizer and pesticides (Tilman et al., 2002), which have polluted ground and surface waters. Intensification of tillage practices have depleted C stocks in agricultural soils (Lal, 2011a).

To face these issues, the "ecosystems approach" has been proposed by many international organizations (i.e. FAO, OECD, UNEP). The Convention on Biological Diversity (CBD) defined the "ecosystem approach" as the importance of managing ecosystems to maintain ES for humans. The Millennium Ecosystem Assessment (MEA, 2005, 2003) developed this principle into a framework of ES in order to evaluate the consequences of ecosystem change for human well-being. According to this framework (MEA, 2003), ES are classified in four categories: *supporting services* ("services necessary to the production of all other ES"), *provisioning services* ("products obtained from ecosystems"), *regulating services* ("benefit obtained from regulation of ecosystem processes") and *cultural services* ("non material benefit obtained from ecosystems").

Soil management is fundamental to all agroecosystems (Lal, 2010; Powlson et al., 2011) and affects ecosystem processes that are involved in ES provision (Power, 2010). Because food and energy production depend on soil for the provision of these services (Costanza et al., 1997; Karlen et al., 2003) it is seen as essential to include soil ES into the MEA framework to inform agricultural and environmental policies (Breure et al., 2012; Dominati et al., 2010; Robinson et al., 2013). There is an ongoing debate about the extent to which soil management can contribute to increase sustainability of agricultural production. On this regards, reliance on soil ES instead of synthetic, non-renewable inputs is

* Corresponding author.
E-mail address: andrea.ferrarini@unicatt.it (F. Andrea).

http://dx.doi.org/10.1016/j.apsoil.2017.06.031
Received 18 February 2017; Received in revised form 19 June 2017; Accepted 22 June 2017

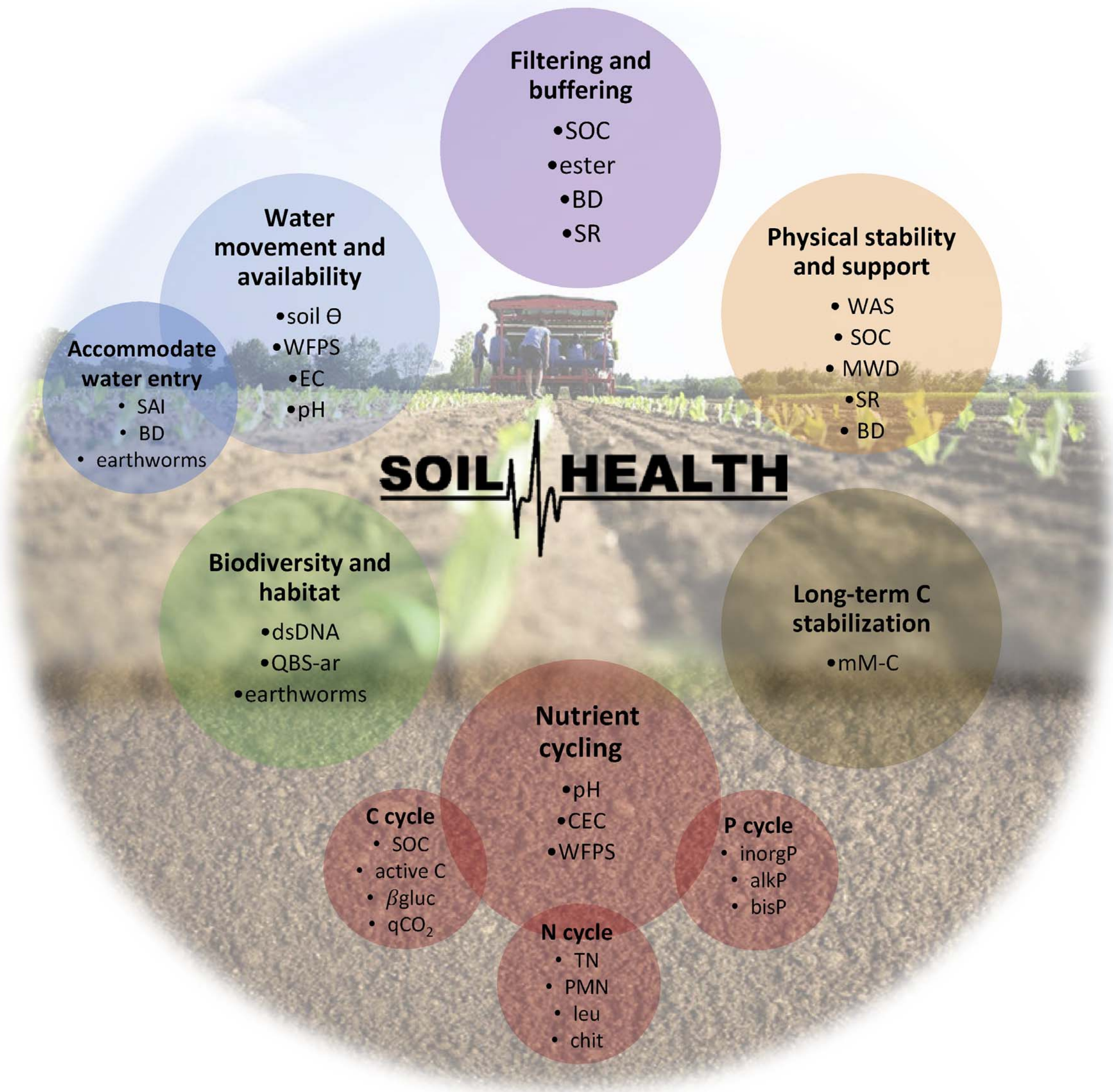

Fig. 1. Indicator framework for assessing the impact of soil management practices on overall soil health and soil ES (circles). Soil health is assessed through the combination of a minimum data set (MDS) of indicators into a composite soil health index (SHI) (Andrews et al., 2004; Ferrarini et al., 2014; Moebius-Clune et al., 2016). Indicator key: (SOC) soil organic C; (ester) acetate esterase enzyme activity; (BD) bulk density; (SR) basal soil respiration; (WAS) water aggregate stability; (MWD) Mean Weighted Diameter; (mM-C) C content in microaggregate-within-macroaggregate fraction (Six and Paustian, 2014); (CEC) Cation Exchange Capacity; (WFPS) Water Filled Pore Space; (active C) $KMnO_4$ oxidizable C; (??gluc) beta-glucosidase activity; (qCO_2) metabolic quotient; (TN) Total Nitrogen, (PMN) Potentially Mineralizable Nitrogen, (leu) leucine aminopeptidase activity, (chit) N-acetyl glucosamine activity; (inorgP): available inorganic P; (alkP) alkaline phosphomonoesterase activity; (bisP) phosphodiesterase activity; (dsDNA) dsDNA content (Fornasier et al., 2014); (QBS-ar): microarthropods-based soil quality index; (SAI) Stable Aggregate Index; (soil Θ) soil porosity; (EC) Electrical Conductivity.

seen in the last years as a key to achieving food and energy security in a sustainable way (Barot et al., 2017; Bommarco et al., 2013). This approach is known as ecological intensification of agriculture and its main objectives is to sustainably use the multiple ES of agroecosystems to support resource-efficient production (Bender et al., 2016; Tittonell, 2014). One basic principle of ecological intensification is that soil is considered as a living system and as such is distinguished from parent material mainly by its biology. Agricultural soils are the habitat for different key functional organisms (Brussaard et al., 2007) which collectively as soil biota contribute to soil ES provision (de Vries et al., 2013; Wall et al., 2004). For example, soil macrofauna, especially earthworms, have important impacts on SOM dynamics and nutrient cycling. The soil ES include the ecosystem processes that support the production of biomass such as nutrient cycling and regulate water flow and quality, the greenhouse gases (GHG) emissions and the biological control of pests and diseases (Adhikari and Hartemink, 2016).

In the last decade, soil ES have gained popularity within the academic community (Breure et al., 2012; Fisher et al., 2009) and started to be accepted by soil science community (Dominati et al., 2010; Robinson et al., 2013). Comprehensive frameworks to assess the effect of agricultural practices on soil ES and disservices are now available (Barot et al., 2017; Clothier et al., 2011; Dominati et al., 2014; Orwin et al., 2015). The concept of soil ES is also a matter of great political relevance since it has been adopted by multilateral environmental agreements such as the Global Bioenergy Partnership (GBEP) and the FAO-Global Soil Partnership. The European Union has expressed the "soil ES approach" in several policies, e.g. in the EU Soil Thematic Strategy and in Common Agricultural Policy 2014–2020. After the declaration by United Nations of 2015 as the International Year of Soil Wall and Six (2015) reminded how at global scale soil security is now a priority. As a results of this increasing awareness on soil ES, in an attempt to institutionalize soil management at all levels a straightforward message was launched by the revised World Soil Charter (FAO, 2015): "healthy soils are a basic prerequisite to meeting varied needs for food,