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Impact of secondary vegetation succession on soil quality in a humid Mediterranean landscape

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ABSTRACT

Former agricultural fields are increasingly abandoned in several regions in Southern Europe. In many cases this leads to vegetation succession which may have a direct impact on soil quality, biodiversity and hydrological connectivity. The aim of this study is to provide insights on the role of vegetation succession in response to land abandonment on soil quality changes, while keeping aspect into consideration. Information on soil quality change is incomplete and highly scattered especially in the Mediterranean and deserves more attention.

Four different stages of land use change and vegetation succession (i.e. agricultural field, abandoned field, young forest, semi-mature forest) were selected and sampled on both north-, and south-facing slopes. For each of the eight conditions six representative sites were sampled. During vegetation succession soil organic carbon (SOC) content and total nitrogen (TN) content, and aggregate stability significantly increased. With increasing SOC, TN and aggregate stability the bulk density and pH decreased. In addition, the parameters SOC, TN and water retention are impacted by aspect. SOC contents increased slower over time on north exposed slopes, but were higher after 50 years. Carbon stocks showed a similar trend but were not different after 50 years for both studied expositions, due to aspect related changes in dry bulk density over time. Soil water availability was 24% higher for north-facing slopes. Soil water availability however did not change over time. Largest increase in soil quality was observed in the first 30 years after abandonment.

1. Introduction

Since the Second World War, in several regions in southern Europe a trend of decreasing agricultural activity can be observed as a result of socio-economic changes (García-Ruiz and Lana-Renault, 2011; MacDonald et al., 2000; Keesstra, 2006). Former agricultural fields are abandoned which may lead to land degradation and desertification, and in many cases secondary vegetation succession occurs which may alter the resilience and response of the ecosystem (Cerdà, 1997; Geeson et al., 2002; Cammeraat et al., 2005; García-Ruiz et al., 2005). The restoration of soil quality after soil degradation due to unsustainable land use is of crucial importance to maintain or improve ecosystem services for future generations (Montanarella, 2015; Keesstra et al., 2016), as soil forms an essential part of the water-food-soil nexus (de Paul Obade and Lal, 2016). Therefore it is essential to understand the rate at which soil quality indicators change due to degradation, and under which conditions these changes can be reverted when the conditions in terms of land use improve. Soil quality is closely linked to soil carbon which has great importance to the global carbon cycle (Quinton et al., 2010). Although much effort has been put in studying soil organic carbon (SOC) stocks, the information on SOC stocks change under secondary succession in the various global ecosystems is highly variable and needs further extension, especially in the Mediterranean (Novara et al., 2014; Trigalet et al., 2016). Soil quality also regulates soil water dynamics and infiltration and as such play an important role in the availability of fresh water resources. Current developments in land use change also predict a further increasing land abandonment and rewilding of Europe (Navarro and Pereira, 2015). In this study we looked in detail into soil quality changes as a result of natural reforestation during secondary succession in different stages of development, in areas that have been abandoned since the Second World War in the SW of Slovenia.

The impact of clearing and cultivation of natural forest on soils has been studied by various authors (e.g. Islam and Weil, 2000; An et al., 2008). The effects of reverse land cover change, i.e. secondary vegetation succession, leading to a forest cover, has recently also received more scientific attention, however, the information is highly scattered and ecosystem dependent. Also information on the role of slope exposition on soil quality change after abandonment is scarce, which is strange as vegetation development and soil moisture dynamics are very important, especially in the Mediterranean. Secondary vegetation succession

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and subsequent soil quality improvement generally proceed slowly (Ruiz-Sinoga and Martinez-Murillo, 2009). The impact of change is important with respect to ecosystems response and soil carbon storage and should be studied over the full time span from abandonment to full grown forests, to be able to evaluate their impact, also to anticipate on climate change and the predicted continuation trend of land abandonment.

When abandoned agricultural land changes back into forest under secondary succession, also soil properties will change (Lesschen et al., 2008; Nadal-Romero et al., 2016) and will affect nutrient cycling mechanisms, soil organic matter accumulation and the hydrological response (García-Ruiz et al., 2005; Keesstra, 2006; Novara et al., 2014; Gabarrón-Galeote et al., 2015). It is well known that standard agricultural practices generally, like tillage, have a negative impact on SOC (Cerdà et al., 2009). Grasslands under comparable conditions tend to have a higher amount of SOC at the surface than cultivated fields (Post and Kwon, 2000; Deng et al., 2016), due to high (root) biomass organic matter input, slow decomposition of plant debris and the lower removal of biomass during harvest. Tillage management increases microbial decay of plant residues, leading to higher mineralisation and lower SOC levels (Guzman and Al-Kaisi, 2011). In forested areas the above ground input of litter as well as roots represents a large percentage of the soil's total organic input (Kalbitz et al., 2007; Huang and Spohn, 2015), and organic-rich surface layers are likely to develop during secondary succession and the climax vegetation. Furthermore these organic-rich surface layers may contain nutrients which have been extracted from deeper soil layers and enter the soil layer through biological incorporation of litter into the top mineral horizons (Sauer et al., 2012). In general, secondary regrowth, leading to a forest cover, causes a progressive recovery of SOC (Post and Kwon, 2000), which is studied most widely and seen as the most important soil quality indicator (Nunes et al., 2012). In addition, vegetation cover, water retention capacity, and aggregate stability increase progressively after abandonment and successive vegetation development (Lesschen et al., 2008).

With increasing litter input, as a result of the vegetation succession, Total Nitrogen (TN) and SOC content are expected to increase. For semi-arid environments Lesschen et al. (2008) found that soil properties are able to recover to their level from before cultivation, but the recovery is slow. Even after 40 years SOC content was still lower compared to semi natural sites. Nadal-Romero et al. (2016) found that for a sub-humid Mediterranean area after 60 years even reforested areas did not reach the same level of SOC and soil quality of natural forests. Knops and Tilman (2000) predicted that recovery to 95% of the pre-agricultural levels of SOC would take 230 years for SOC. Foote and Grogan (2010) found that time for recovery of SOC after abandonment was a more important factor than soil type for a temperate ecosystem.

Another crucial indicator for soil quality is bulk density, which influences plant root penetration, water- and air-filled pore space, biological availability of nutrients and infiltration (Karlen et al., 1997). Aggregate stability, structure, vegetation (i.e. plant type and cover, SOC content), and topographic and climatic influences all play a role in controlling infiltration rate and capacity of a soil (Yimer et al., 2008). With bulk density changes over time after abandonment, also the pore size distribution of the soil changes, affecting the water holding capacity of soils.

Slope aspect is an important factor influencing local micro-climates, mainly due to the difference in solar radiation. This generally causes north-facing slopes to be cooler and moister compared to south-facing slopes. Lower soil temperature and less moisture evaporation cause less decomposition of soil organic matter (e.g. Rezaei and Gilkes, 2005; Gong et al., 2007; Begum et al., 2010). Therefore soil organic matter and the status of many soil nutrients (e.g. N, P), and with this the fertility of the soil, is generally better at north-facing slopes, compared to south-facing slopes (Gong et al., 2007).

The aim of this study is to provide insight on how of vegetation succession affects soil quality in response to land abandonment. This will be evaluated by looking at the temporal changes in SOC, SOC stocks, TN, bulk density, aggregate stability, pH, water retention and soil texture as key parameters for soil quality for three stages of land abandonment (10 years, 25 and 50 years after abandonment) and on contrasting northern and southern exposed slopes.

2. Study area

The study area is situated in the southwestern part of Slovenia and part of the 91 km^2 Dragonja catchment (Fig. 1). The 30 km long Dragonja river flows from east to west into the Gulf of Trieste in the northern most part of the Adriatic Sea. Therefore most hill slopes are north-, or south-facing. Elevations of the catchment range from 484 m to sea level. The upper part of the catchment, which is the actual study area, consists of the Rokava sub-catchment (20 km^2) to the north, and the Upper-Dragonja sub-catchment (32 km^2) to the south (Keesstra, 2006).

The climate of the study area is characterized as sub-Mediterranean (Köppen-type Cfa; Ogrin, 1996), with average January temperatures between 0 and 4 °C, average July temperatures between 19 and 22 °C, and average annual temperature just above 10 °C. In the study area average yearly precipitations is between 1100 and 1200 mm, with app. 40% of precipitation in fall and with app. 20% of precipitation in other seasons (Zorn, 2012).

The substrate in the catchment consists mainly of sub-horizontal impermeable Eocene flysch beds (Zorn, 2009), which consist of highly erodible and calcareous clay- and siltstones, with intermittent sandstone layers with a maximum thickness of 1.5 m.

The catchment consists of long flat ridges (up to 400 m above sea level) above deep and narrow river valleys, where most settlements have developed (Zorn and Petan, 2008). In the Upper Dragonja sub-catchment valleys are narrow and the aspect of the slope does not affect its steepness. In the Rokava sub-catchment however, north-facing slopes are much steeper than south-facing slopes and the valley is wider (Keesstra, 2006). The soils in the valley are calcareous.

The catchment has been cultivated for a long period, probably since Roman time (Keesstra, 2007). Due to socioeconomic changes since the Second World War depopulation and abandonment of farming has occurred in the catchment and with this a breakdown of the cultural landscape. This was followed by natural reforestation (Urbanc, 2008; Keesstra et al., 2009a, 2009b). The cover by forest increased in the upper part of the catchment where the study area was from around 30% in the mid-1950s to >60% the Rokava sub-catchment and >70% in the Upper Dragonja sub-catchment about a decade ago (Keesstra, 2007).

3. Methods

3.1. Sample design and collection

Fields with different phases of secondary succession ranging from agricultural fields to mature forests, with two opposing aspects were studied. We applied space for time substitution (Paine, 1985; Cammeraat and Imeson, 1998) as the fields selected were comparable with regard to lithology, slope angle, soil type and former land use (vineyards). This approach is often adopted in soil quality research and especially in SOC studies as soil quality indicators only slowly change over time (e.g. Martinez-Fernandez et al., 1995; West and Post, 2002; Ruiz-Sinoga and Martinez-Murillo, 2009; Novara et al., 2014; Trigalet et al., 2016). In the summer of 2013 topsoil samples have been taken in the study area (upper 10 cm). The samples were collected in vineyards, abandoned fields, young forests and semi-mature forests, representing the four stages (age group 0–3) of vegetation succession. Age group 0 reflects current agricultural use; age group 1 reflects 5–10 year abandonment and age group 3 and 4 cover 25 and 50 years of abandonment respectively. As an additional condition,