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Shrub encroachment by green alder on subalpine pastures: Changes in mineral soil organic carbon characteristics

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ABSTRACT

Shrub encroachment by green alder (*Alnus viridis*) has been an ongoing process in European mountain areas after land abandonment. The invasion of this N_2-fixing and highly productive plant on former subalpine pastures and meadows changes the properties and interactions in the plant-soil system. In the national carbon inventory, it is assumed that green alder woodlands contain the same amount of SOC (~69 t C ha^{-1}) as productive forests due to the lack of data. To explore the rarely studied change of the soil organic carbon (SOC) pools during the shrub establishment, the study used a chronosequence approach by testing pastures in a pre-encroached status and green alder stands with an age of 15, 25, 40 and 90 years, respectively. Besides the estimation of the SOC stock, the soil samples, taken in four different depth layers, were physically fractionated to characterize the quality of the SOC. While pasture grassland contained a median SOC stock (0–30 cm) of 100 t C ha^{-1}, the SOC stocks decreased to 81 t C ha^{-1} for 40 years old shrub stands. The 90 years old green alder bushes showed the significantly highest C stock in the mineral soil with 174 t C ha^{-1}. Green alder encroachment led to an increase of the particulate organic material (POM) in the mineral soil resulting in a high concentration of unprotected carbon. By contrast, a stabilization of the SOC with the mineral soil phase was not visible during green alder establishment. The study concludes that green alder encroachment causes a significant increase of fresh and unprotected carbon in the soil system compared to subalpine pastures, resulting in a significantly higher total SOC stock (+74 t C ha^{-1}) after 90 years and a doubling of the potential to leach dissolved organic carbon. At landscape level, the ingrowth and establishment of green alder on abandoned subalpine pastures can therefore influence the terrestrial and aquatic systems. Secondly, the SOC stocks of shrub forests are insufficiently represented in the current National Inventory Report.

1. Introduction

1.1. Land abandonment and forest regrowth in the European Alps with a focus on Switzerland

Over centuries, traditional agricultural cultivation forms generated a unique landscape of high ecological value in the European Alps (Gellrich and Zimmermann, 2007). The resulting landscape is characterized by broad parts of man-made meadows and pastures (Tasser et al., 2011).

During the 20th century political, economic and social changes led to an alteration of the agricultural structures (Flury et al., 2013). Thus, between 1980 and 2000 about 33% of the farm holdings and 4329 km^2 (−7.6%) of the agricultural used area have been abandoned within the Alpine arc (Streifeneder et al., 2007; Streifeneder, 2009). In the Swiss Alps, 39% of farms disappeared between 1985 and 2009 (BfS, 2013). As a consequence, the area of sub-/alpine summer pastures in the Swiss Alps decreased by 372 km^2 (−34.5%) (Schubarth and Weibel, 2013).

Land abandonment is the main driver for forest and shrub regrowth in the Alps which was observed in a wide range of regional studies throughout the whole Alpine arc (Bebi and Baur, 2002; Anthelme et al., 2003; Gellrich et al., 2007; Gehrig-Fasel et al., 2007; Camacho et al., 2008; Cocca et al., 2012; Huber and Frehner, 2013; Pellissier et al., 2013; Caviezel et al., revised). The Swiss National Forest Inventory (NFI) recorded an expansion of the shrub forest of 113 km^2 (+21%) for the Swiss Alps (NFI categories “Alps” and “Southern Alps”) between the observation periods 1983/85 and 2009/13 (WSL, 2015a, 2015b). This increase was proportionally higher than the regrowth of mature forests (+18%) (WSL, 2015a, 2015b). Currently, shrubs cover an area of about 644 km^2 in the Swiss Alps (WSL, 2015b). Besides dwarf mountain pine (*Pinus montana* subsp. *prostrata* Tubeuf), hazel (*Corylus avellana* L.) and various willow species, 70% of the shrub forest area consists of green alder (*Alnus viridis (Chaix) DC = Alnus alnobetula (Ehrh.) K. Koch*).

A. viridis is an early successional and fast expanding species (Cioldi

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et al., 2010). According to Schröter (1908) and Richard (1968), green alder is naturally restricted to steep, north facing subalpine well drained slopes and debris flow tracks. However, recent studies in the eastern and central parts of Switzerland have shown, that the ecologic niche of green alder is much wider than assumed and that the abundance of green alder is mostly controlled by land use intensity (Huber and Frehner, 2013; Caviezel et al., revised). Consequently, green alder bushes have the potential to spread on abandoned subalpine pastures and influence the vegetation and soil system of larger areas than presumed so far (Caviezel et al., revised).

1.2. Impact of green alder encroachment on carbon stocks, carbon quality and soil properties

Available data for common carbon pools of the shrub forest or even for the green alder is sparse. Thus, the National Inventory Report (NIR) assesses equally the carbon stock values of productive forests and those of shrub forests (69 t C ha^{-1}), except for the living above-ground biomass pool (FOEN, 2015). For the green alder species, Bühlmann et al. (2016) recently reported 26 t C ha^{-1} in the above-ground biomass, 8 t C ha^{-1} in the below-ground biomass, 1 t C ha^{-1} in the fresh litter and 62 t C ha^{-1} in the mineral SOC stocks for bushes growing at 1650 m asl. The annual biomass productivity of green alder communities was estimated to be 6 t ha^{-1}, which is higher compared to other subalpine vegetation species such as *Picea abies* and *Betula pendula* or grassland (Wiedmer and Senn-Irlet, 2006; FOEN, 2014, 2015; Bühlmann et al., 2016). The different biomass production of *A.viridis* communities consequently results in a change of the quantity and quality of litter material as well as the carbon contained in the litter when pasture land turns into green alder shrubland (Jackson et al., 2007). Furthermore, under the newly established green alder bushes, the decomposition of the litter and its residues is hampered by i) the cool and moist conditions due to the shade of green alder canopies (Bühlmann et al., 2014, 2016) and ii) the increase of the C/N ratio due to the higher proportion of woody material, which is unfavorable to the detritus consumers (Jackson et al., 2007; Bühlmann et al., 2016) (Fig. 1).

The ingrowth of green alder on abandoned grassland areas strongly influences the soil properties and its quality, hence the ecosystem services, from a more eco-pedological perspective (Bühlmann et al., 2014; Caviezel et al., 2014; Hiltbrunner et al., 2014; Bühlmann et al., 2016) (Fig. 1). Due to the symbiosis between *A. viridis* and the actinomycete ***Frankia alni***, the soil experiences an enrichment of nitrogen (Bühlmann et al., 2014). Thus, the soil processes under green alder stands are hardly comparable to those under forest or other vegetation types. The soil nitrogen enrichment by N_2 fixation can hamper the succession of coniferous species and the green alder vegetation type can build a long persisting climax vegetation due to unfavorable soil nutrient composition (Anthelme et al., 2002; Huber and Frehner, 2013; Hiltbrunner et al., 2014). The increased N pool also creates the potential for nitrate leaching to water bodies (Bühlmann et al., 2016; Mueller et al., 2016).

Another possible change in soil chemistry induced by green alder is the substantial decrease of the pH value and thus, the base saturation of the encroached soil as a consequence of the nitrogen enrichment and the proton production during the nitrification process under green alder stands (Podrazsky et al., 2003; Caviezel et al., 2014; Bühlmann et al., 2016). Green alder encroachment also leads to a decline in root density while soil porosity and SOC concentration increase (Caviezel et al., 2014) (Fig. 1).

1.3. Aims and objectives of the study

The on-going green alder encroachment potentially leads to an unprecedented change in the soil conditions that is difficult to compare to other types of land cover and change. Further, the ingrowth can affect the sequestration and hence the residence time of the soil organic matter components in different functional pools which are characterized by distinctive stabilization mechanisms (von Lützow et al., 2007; Schmidt et al., 2011). Due to the strong linkage between the biomass as well as litter characteristics and the SOC, there is need to fill these knowledge gaps regarding the change of the SOC quantity and quality during the establishment of *A. viridis* shrubland. Additionally, other soil properties might be influenced by the establishment of high-productive green alder shrubland and hence the expected SOC changes.

The present study therefore aims to answer the following research questions (i) What happens to the SOC stock during the encroachment process by green alder? (ii) Is the SOC stock of green alder stands

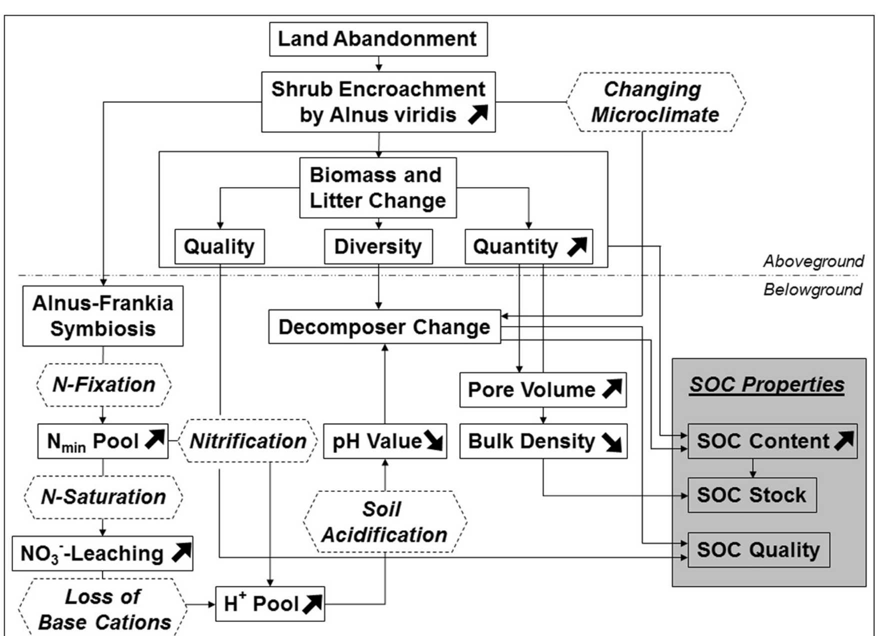

Fig. 1. The hypothetical model shows how the SOC properties are influenced by the *A. viridis* encroachment hence, other soil properties and processes (italic). Based on the findings of Caviezel et al. (2014), Bühlmann et al. (2016) and Caviezel et al. (revised), the arrows show the direction of measured changes induced by the green alder encroachment.