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Soil properties and charcoal dynamics of burnt soils in the Tyrolean Limestone Alps

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ABSTRACT

We investigated soil samples of four burnt slopes in the Tyrolean Limestone Alps of varying age after fire (wildfires occurred in 2003, 1962, 1946, and in 1250 AD) as well as of the surrounding soils that were not affected by combustion. Charcoal content of the O and A horizons was determined as well as pH, soil organic matter content and C/N ratio. The results showed a background value of charcoal in all soils with a dominance of charcoal in the O horizon of the youngest burnt slope (2003). With vegetation and soil recovery, charcoal concentrations decreased and zones of maximum charcoal accumulation shifted further down in the soil profile. Soil organic matter contents significantly decreased on burnt slopes, which is due to vegetation combustion, long-term vegetation changes and intensified erosion. However, in the long-term, re-accumulation occurs due to the recovery of vegetation. Soil pH increased by combustion and was further modified by an altered vegetation composition. C/N ratios remained largely stable, with the soil N content reacting more sensitive to combustion. The results demonstrate that Alpine regions react sensitively to wildfires due to the steep slope angle, which causes not only short-term but also long-term modification in vegetation composition and erosion.

1. Introduction

Wildfires are known to have considerable impact on ecosystems, with relaxation times ranging from a few years to decades or even centuries. Altered physical and chemical soil properties, such as loss or gain in available nutrients and soil organic matter (SOM), increased mean topsoil temperature and intensified soil erosion are key parameters for vegetation development after fire (DeBano et al., 1998; Miller, 2000). SOM is highly affected by wildfires and can both increase or decrease (Mataix-Solera et al., 2002, 2011). Santín et al. (2008) investigated wildfire influence on SOM and found that SOM stocks may increase after fire due to enhanced litter production from damaged vegetation and decreased microbial SOM mineralisation. Johnson and Curtis (2001) also detected an 8% rise of the SOM content caused by the accumulation of stable organic compounds. On the other hand, there is an immediate reduction of SOM due to volatilisation (Boerner, 2006). Furthermore, enhanced solar irradiation due to vegetation loss can increase mineralisation rates (Kasischke and Johnstone, 2005) and may release three times more C than the combustion process itself (AuClair and Carter, 1993), therefore causing significant fire-induced SOM losses. Hasselquist et al. (2011) found a loss of organic C due to increased aeolian transport after a wildfire as well as a reduction in litter production.

Aggregation stability may be reduced after combustion due to SOM losses (Fernández et al., 2005; Mataix-Solera et al., 2011), resulting in reduced topsoil stability and therefore promoting erosion particularly in mountainous regions. SOM reduction decreases the infiltration capacity while the reduced vegetation cover intensifies the splash effect. Ash and charcoal that form during combustion may clog the soil pores, thus reducing infiltration and further promoting surficial runoff. Typically, a hydrophobic layer forms that impedes infiltration and aggravates erosion in the first few months after the fire (e.g. DeBano et al., 1998; Neary and Ffolliott, 2005). Additionally, organic matter has an absorbing function influencing the nutrient availability (DeBano et al., 1998) and thus, intense wildfires cause nutrient losses depending on wildfire temperature, moisture content and vegetation composition (DeBano et al., 1998). N and P are easily volatilised whereas K, Ca and Mg frequently remain as ash on the burnt soil (Boerner, 2006). The basic cations Ca and Mg are transformed into plant available compounds (alkaline oxides) entailing an ash bed effect and higher pH values (Blankenship and Arthur, 1999). Giovannini et al. (1990) consider the pH value development caused by wildfire to be dependent on the combustion temperature; higher temperatures (>460 °C) during the fire cause a pH increase whereas lower temperatures (<220 °C) generate a pH decrease. Long-term N loss also emerges if the humus decomposition rate rises due to altered soil temperature conditions (Kasischke and Johnstone, 2005). However, residual anorganic N compounds may be increasingly plant available for the short term (Kutiel et al., 1990; Wan et al., 2001). Higher nitrate contents after a wildfire appear because of increased nitrification rates (Boerner, 2006) and decreased

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plant uptake. Consequently, wildfires affect the C/N ratio to a variable extent depending on whether SOM losses or gains occurred and to what extent nitrogen has been volatilised. In addition to SOM losses or gains that both may occur as explained above, SOM quality may also change. After a wildfire, SOM may become more aromatic and hence, the affected soils may be less prone to erosion (Gonzàlez-Pérez et al., 2004; Mataix-Solera, 2011).

Furthermore, burnt soils are typically characterised by elevated charcoal concentration. The wide variety of compounds commonly referred to as black carbon (BC) results from lignin degradation during pyrolysis due to incomplete combustion (De la Rosa et al., 2008) and have been considered to be very stable (DeLuca et al., 2006; Glaser et al., 2002). Recently, their stability concerning physical and microbial decomposition has been contradicted by several authors (Knicker, 2007; Rovira et al., 2009). The question for BC stability in soils is important for carbon budgets: Wildfires are considered as a middle-term atmospheric carbon source due to CO_2 release during the combustion process (Crutzen and Goldammer, 1993). At the same time, burned soils are regarded as carbon sinks due to the formation of stable organic C and increased litter accumulation (Santín et al., 2008).

Even though fires are common along the southern fringe of the European Alps (Delarze et al., 1992; Pezzatti et al., 2009; Tinner et al., 1998) and in parts of the central Alps (Stähli et al., 2006), the Northern Alps have not been commonly known to be significantly affected by wildfires. However, fires are widespread along the south-exposed slopes of the Inn valley and the surroundings, where frequent foehn winds especially in spring and autumn can lead to very dry weather conditions. The resulting fires can cause long-lasting impacts on vegetation, soil and geomorphic dynamics (Sass et al., 2006, 2012). Soils in the subalpine Northern Limestone Alps are often characterised by thick organic layers reaching ages of several thousands of years and containing large amounts of SOM, resulting from subdued decomposition rates due to low temperatures, edaphically dry conditions and less decomposable litter (Djukic et al., 2010; Hobbie et al., 2000; Simmons et al., 1996). Furthermore, rendzic leptosols with organic layers of different thickness are widespread. A unique feature of these study sites is the fact that soils can even be totally destroyed by fire if the organic layer is burned and the remaining material is washed down on steep slopes (Sass et al., 2006) resulting in large SOM losses. However, short- and long-term effects of fire on these soils are largely unknown. In our study we tried to answer the following questions:

- Which amounts of charcoal are produced, and how are they displaced and decomposed with increasing time after fire?
- To what extent are the selected soil parameters (SOM, pH, C and N contents) influenced by fire, and how do these properties develop with increasing age after fire?
- How do wildfires generally affect soil development in the northern Alps?

2. Study sites

2.1. Wider study area

The study sites are located in the Karwendel Mountains, a mountain range in the Tyrolean Limestone Alps north of Innsbruck (Fig. 1). The mean annual temperatures are ca. 9.1 °C in the valleys (Innsbruck, 577 m) and around 0 °C at an elevation of 2300 m (Meteorological station Patscherkofel, 2245 m, 0.2 °C). The south-exposed slopes can, however, show higher temperatures due to considerable radiation input (Prietzel, 2010). Precipitation decreases from the north (Achenkirch: 1445 mm) to the south (Innsbruck: 889 mm) and increases considerably with elevation (Bettelwurfhütte/Halltal, near Innsbruck, 2100 m: 1806 mm) (data taken from Tirol Atlas, 2007). Very dry foehn winds particularly occur in winter and spring thus, the main fire season is in the spring months due to a superposition of dry weather and fuel abundance (Vacik et al., 2011). By means of historical investigations we have found more than 400 wildfire slopes in the area to date (Fig. 1). From the dataset we calculated a point mean fire interval (PMFI) of 9400 years for the entire area which means that fires are rare, singular events within most parts of the region. However, on some of the south-exposed slopes the PMFI decreases to c. 500 years (Sass et al.,

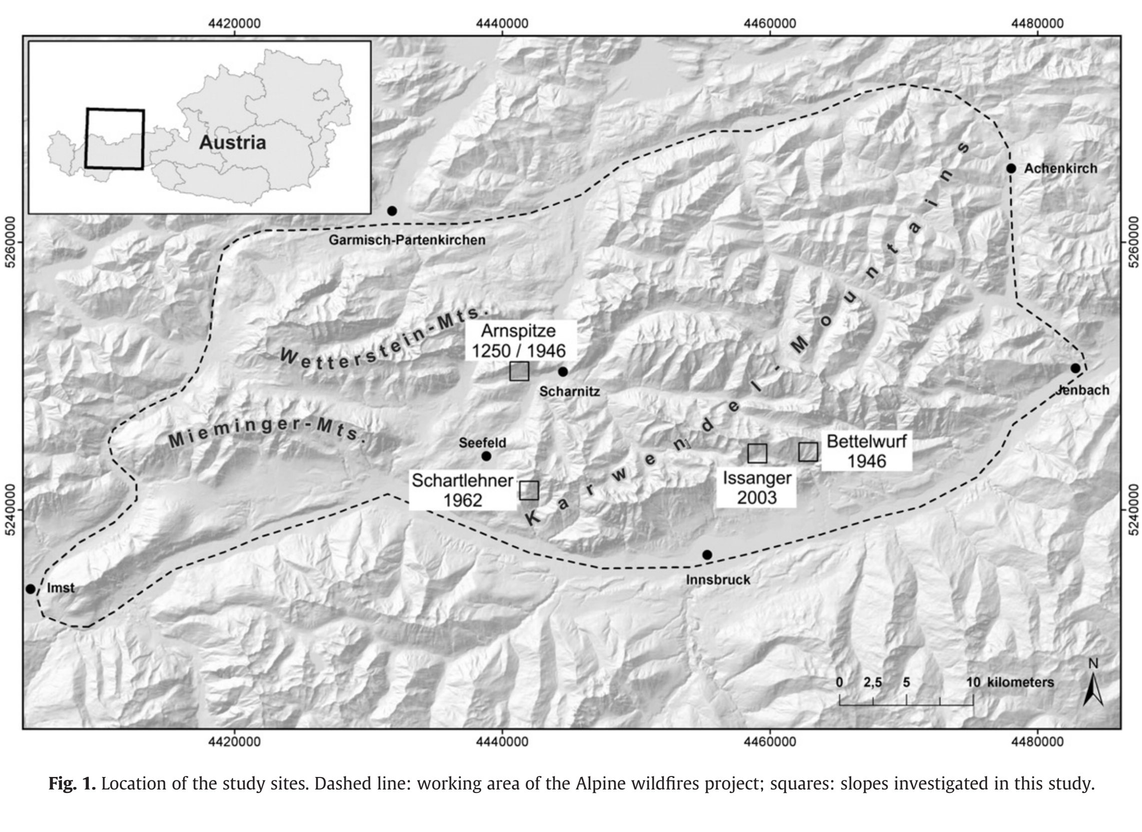

Fig. 1. Location of the study sites. Dashed line: working area of the Alpine wildfires project; squares: slopes investigated in this study.