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Carbon sequestration and fertility after centennial time scale incorporation of charcoal into soil

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The addition of pyrogenic carbon (C) in the soil is considered a sustainable strategy to achieve direct C sequestration and potential reduction of non-CO_2 greenhouse gas emissions. In this paper, we investigated the long term effects of charcoal addition on C sequestration and soil chemico-physical properties by studying a series of abandoned charcoal hearths in the Eastern Alps established in the XIX century. This natural setting can be seen as an analogue of a deliberate experiment with replications. Carbon sequestration was assessed indirectly by comparing the amount of C present in the hearths with the estimated amount of charcoal that was left on the soil after the carbonization. Approximately 80% of the C originally added to the soil via charcoal can still be found today, thus supporting the view that charcoal incorporation is an effective way to sequester atmospheric CO_2. We also observed an improvement in the physical properties (hydrophobicity and bulk density) of charcoal hearth soils and an accumulation of nutrients compared to the adjacent soil without charcoal. Then, we focused on the morphological and physical characterization of several fragments, using scanning electron microscopy (SEM), X-ray diffraction (XRD) and X-ray fluorescence (XRF). Such study enabled the identification of peculiar morphological features of tracheids, which were tentatively associated to a differential oxidation of the structures that were created during carbonization from lignine and cellulose. In order to assess the effect of soil-aging we compared the old-biochar with a modern one obtained from the same feedstock and with similar carbonization process. XRD and XRF analysis were performed on both old and modern biochar, in order to study the multiphase crystalline structure and chemical elements found. We observed mineralization and a fossilization of old biochar samples respect to the modern ones, with accumulation of several mineral oxides and a substantial presence of quartz. A graphene structure was also found, indicating weak bonds in the carbon structures, explained by inter-molecular Van der Waals forces. Furthermore, we have detected a graphite oxide structure responsible of the bending effect in the tracheid, revealed in SEM images. We consider that those results may contribute to the ongoing debate on the best, most suitable geo-engineering strategies that can potentially enable effective and sustainable carbon sequestration in agricultural soils using biochar.