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Wildfire Ash: Chemical Composition, Ash-Soil Interactions and Environmental Impacts

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Of the five classical factors of soil formation, climate, parent material, topography, time, organisms, and recently recognized human activity, it is the latter factor which discretely includes fire and post-burn impact. However, it is considered that soil undergoing fire just experience a temporary removal of the top organic horizon, thus slightly modified and often labeled as 'temporarily disturbed' soil or soil 'under restoration/rehabilitation'. In fact the suggested seventh factor, post-burned produced ash, can act both dependently and independently of the other soil forming factors (Levin et al., 2013; Certini 2013). They are interdependent in cases where ash influences occur on time scales similar to 'natural' soil formation (Keesstra et ai., 2014) such as changes in vegetation. On the other hand, in post-fire areas a strong dependency is expected between soil–water retention mechanism, climate and topography.

Wild-land fires exert many changes on the physical, chemical, mineralogical, biological, and morphological properties of soil that, in turn, affect the soil‘s hydrology and nutrient flux, modifying its ability to support vegetation and resist erosion. The ash produced by forest fires is a complex mixture composed of organic and inorganic particles characterized by vary physical-chemical and morphological properties.

The importance of this study is straightforwardly related to the frequency and large-scales wildfires in Mediterranean region. In fact, wildfires are major environmental and land management concern in the world, where the number and severity of wildfires has increased during the past decades (Bodi, 2013). Certini (2013) assumed that cumulatively all of the vegetated land is burned in about 31 years annually affecting 330–430 Mha (over 3% of the Earth's surface) and wide range of land cover types worldwide including forests, peatlands, shrublands and grasslands. Whereas, the fire is identified as an important factor in soil formation, the produced ash has significant and not always constructive pedological, ecological, hydrological and geomorphological effects and impacts (Shakesby, 2011). Abundant scientific information is assembled either from control fires by collecting samples before and after wildfire event, or conducting laboratory experiments exanimating data under truly isolated conditions (Lugassi et al., 2013). However, an integration and synthesis of the knowledge about ash including deeper understanding of inter-correlation between chemical, physical and morphological compounds in open post-burn environment and its possible interactions in soil formation or impact on soil composition are highly needed.

The main aim of the presented study was to advance the science of soil-fire relationship by recognizing the remains ash as a new soil-forming factor, on par with the traditionally recognized factors: parent material, topography, time, climate, organisms, and recently recognized human activity as the sixth factor. This research was conducted to develop new methods to assess impacts and quantify the contributions/influences of post-fire products, mainly ash, on soil composition and soil properties in post-burned environment. We conducted several controlled experiments using 40 soil samples (typical Mediterranean Rendzina soil, pH 6.84, a grayish-brown, humus- and free calcium carbonate- rich, intra-zonal). The samples include bare soils and different types and loads of forest litter, were exposed to different temperatures (200˚C, 400˚C and 600˚C) in a muffle furnace for 2 hours (Pereira et al. 2011) as fire temperature plays a key role in determining ash properties. The ash produced at a low temperatures (<300˚C) is black, contains >50% carbon and retains many of the structural characteristics of the parent material. At higher temperatures, the residue ash is greyish, consisted of very fine particles that preserve almost none of the original structural characteristics of the fuel (Woods and Balfour, 2008) creating gradient of layered ash with diverse physicochemical properties.

The obtained post-burned soils were processed as following: 1. loss of mass (ML); 2. ash layers sampling – the produced ash layers were collected separately; 3. grinding; 4. color – the Munsell colour chart; 5. spectroscopy– each sample was analysed by two spectrometer, first is the Ocean Optics USB4000 (0.35-1.05 μm) portable system across visible and near infrared (VNIR) region using contact Halogen illumination, second is the Bruker Tensor

II (2.35-25 μm) across mid infrared (MIR) region by Furrier transform IR (FTIR) system using the Pike EasiDiff diffuse reflectance spectroscopy (DRS) optical bench; 6. pH and electrical conductivity (EC) including total dissolve solids (TDS) and salinity (S) measurements. The result of high concentration of carbonates, oxides, and hydroxides of basic cations decreasing EC levels caused by high pH ($>$8) there the $CaCO_3$ surfaces are negatively charged and variation of mineralogical composition introducing very detailed list of minerals (high concentration of Nickeline NiAs, Cuprite Cu_2O, Rehodochrosite $MnCO_3$ and Nitrolite $Na_2Al_2Si_3O_{10}2H_2O$ in the top-layers and mixtures e.g. Kaolinite/Smectite (85% Kaol.) $Al_2Si_2O_5(OH)_4$+(Na,Ca)0.33$(Al,Mg)_2Si_4O_{10}(OH)_2nH_2O$ and Mesolite + Hydroxyapophyllite $Na_2Ca_2Al_6Si_9O_{30}8H_2O$ + $KCa_4Si_8O_{20}(OH,F)8H_2O$ between ash and post-burn top-soil layers.

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