Geophysical Research Abstracts
Vol. 17, EGU2015-11117, 2015
EGU General Assembly 2015


# Evolution of soil properties and metals in acid and alkaline mine tailing ponds after amendments and microorganisms application

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Intense mining activities in the past were carried out in Cartagena-La Unión mining district, SE Spain, and caused excessive accumulation of toxic metals in tailing ponds which poses a high environmental and ecological risk. One of the remediation options gaining considerable interest in recent years is the in situ immobilization of metals. A corresponding reduction in the plant-available metal fraction allows re-vegetation and ecosystem restoration of the heavily contaminated sites. In addition, the use of microorganisms to improve the soil condition is a new tool used to increase spontaneous plant colonization. The aim of this research was to assess the effect of amendments (pig manure, sewage sludge, and lime) and microorganisms on the evolution of soil properties and metals in acid and alkaline tailing ponds and to evaluate the content of metals in Zygophylum fabago one year after amendments application.

The study was carried out in two mine ponds (acid and alkaline). Twenty seven square field plots, each one consisting of 4 m2, were located in each pond. Four different doses of microorganism (EM) (0 ml, 20 ml, 100 ml and 200 ml of microorganism solution in each plot) and one dose of pig manure (5 kg per plot), sewage sludge (4 kg per plot) and lime (22 kg per plot) were used. Organic amendment doses were calculated according to European nitrogen legislations, and lime dose was calculated according with the potential acid production through total sulphur oxidation. Three replicates of each treatment (organic amendment + lime + microorganism dose 0, 1, 2, or 3) and control soil (with no amendments) were carried out. Plots were left to the semi-arid climate conditions after the addition of amendments to simulate real potential applications of the results. Soil samples was collected every 4 month from each plot during one year, after this time Zygophylum fabago plants were sampled from each plots. Soil properties including: pH, salinity, total, inorganic and organic carbon, total nitrogen, total phosphorus, potassium, total, bioextractable and soluble metals (Pb, Cu, Zn, As and Cd), basal respiration and microbial biomass carbon; and metals (Pb, Cu, Zn, As and Cd) in roots and shoot from Zygophylum fabago were analyzed.

The results showed that the lime increased the concentration of inorganic carbon in both ponds and, therefore, increases the pH until neutral/alkaline values, especially in the acid mine pond, reducing the risk of mobility of As, Pb and Zn to the trophic chain and the risk of leaching and runoff. The application of pig manure increased the salinity in the acid mine pond, as well as the content of OC, TN, K and P in both ponds; also it caused a higher concentration of bioavailable and soluble Cu in both ponds due to the high content of Cu in the manure; finally, an higher concentration of bioavailable and soluble As was observed in the alkaline mine pond due to the formation of organic-metal complexes. The application of sewage sludge increased the content of OC and K in both mine ponds; also it caused an increase in the concentration of bioavailable and water soluble As and a slight increase in the water soluble Cu in the alkaline mine pond likely because of the formation of organic-metal complexes.

Both organic amendments increased the microbial biomass carbon (MBC), especially pig manure, indicating that this amendment brings more amount of microorganisms than sewage sludge. Similarly, the application of EM increases MBC, especially in doses 2 and 3, improving soil conditions which favour plant colonization. Furthermore, microbial activity is increased after amendments and EM applications, especially when pig manure was used; indicating that organic matter from pig manure is more easily degradable by microorganisms than organic matter from sewage sludge. Finally, the results indicated that the application of EM promotes the absorption and subsequent translocation to leaves of Cu and As, while prevents the absorption of Cd and Zn in Zygophylum fabago.