Effect of using organic and inorganic amendments on the weathering of overburden from a gold mine

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Introduction

On mining sites, excavation breaks up overburden materials thus exposing the fresh material to weathering. Weathering of overburden is an important process because it may increase the availability of nutrients or heavy metals to plants; elements present in the mineral are released from the crystal lattice as weathering progresses (Bradshaw, 1997).

Aluminium and iron are the two key elements in weathering and pedogenesis processes (Van Hees, Rosling, Lundstrom, and Finlay, 2006), and the common reaction products of chemical weathering are the clay minerals and hydrous oxides of aluminium and iron (Birkeland, 1999). Description of these products is important because of their impact on soil properties; they reflect the long-term effect of the chemical and leaching environment of the soil, and they influence many soil properties (Birkeland, 1999). There will be two main effects; the release of nutrients (cations) and the release of heavy metals from within the crystal lattice.

During weathering processes, organic matter penetrates into the system by means of oxidation (consumption of O_2) and its mineralization (production of CO_2) (Nahon, 1991). Furthermore, the nature of overburden may change due to the application of organic amendments and water regimes through weathering period that could speed up nutrient release and help to overcome other chemical and physical limitations to plant growth.

The objective of this chapter was to investigate the effects of amendments (both organic and inorganic) on the weathering of overburden and hence, the production of a viable growing medium. This was investigated by means of pot trial. The hypothesis was that weathering in combination with amendments would improve the nutritional status of overburden and hence, plant biomass production.

Materials and Methods

The overburden was collected from the current mining exploration site of the OceanaGold-Globe Progress mine site near Reefton, New Zealand. The overburden was air dried, crushed manually, and passed through a 1.5 cm mesh sieve before placing in pots. The pot size used in the experiment had a diameter of 15 cm and was 11.5 cm high. The inside of the pot was covered by a plastic bag and filled with the substrate. Each pot contained 3.5 kg of air-dry overburden.

Four different amendments were used in the experiment; biosolids, lupin as a green manure, N fertiliser, and lime. The biosolids were collected as a fresh biosolid from the Christchurch City Council waste water treatment plant at Bromley, Christchurch, New Zealand three days before use. The N source was analytical reagent grade ammonium nitrate (NH_4NO_3). Lupin plants for green manure were collected from Lincoln University experimental plots (Iversen fields) on the day of application to the pots. Lupin roots were washed with tap water, then the whole plant (shoots and roots) was chopped into 1 cm lengths. The lime source was analytical reagent grade $CaCO_3$ (calcium carbonate). Biosolids, N and lupins were applied at the rate of 200 kg N ha^{-1} which was equivalent to 1 g N pot^{-1}, fresh weight biosolid (water content 80.33%) was 31.5 g pot^{-1}, lupin was 56.43 g pot^{-1}, and lime was 86 g pot^{-1}. The pot trial was conducted in the glass houses of Lincoln University for 24 weeks (May 2007 to January 2008), with a maximum temperature of 25^{o}C and minimum of 14^{o}C. Throughout the experiment, plants were watered to field capacity (-32 kPa). The trials were set up as a randomised block design (1 substrate x 5 soil amendments x 4 water treatments x 1 plant = 20 treatments) with four replicates of each treatment.

The experiment was divided into 2 phases. In the first phase, the overburden was incorporated with amendments and then subjected to four different short-term weathering regimes for six months. The different weathering regimes are not discussed further in this abstract. To provide baseline data, 200 g pot^{-1} of material was sampled prior to the incubation period; this is referred to as T_o in the results section. At the end of the 6 month period, sampling at this time point is referred to in the results section as T_i. The second phase of the experiment commenced at the end of the T_i. In the second phase, Lupin was planted (5 seeds per pot, thinned to 3 plants after 21 days) in the treated substrates and grown for 8 weeks to measure plant responses to the weathering regimes instigated in the first phase. Sampling at this time point is referred to in the results section as T_h. In phase 2, the water status of all substrates was maintained at 90 % field capacity to provide ideal growing conditions for the plants. The Lupin plants were harvested after 60 days. Each plant was carefully separated and washed from the growth medium according to the procedure determined.

Results and Discussion

Cations: During weathering, among the organic amendments used, application of lupin as a green manure was the most effective amendment for increasing the exchangeable cation concentration in the overburden (Fig. 1). This is an indication that lupin green manure was the most effective amendment for increasing weathering of the primary mineral lattice. A possible mechanism for the enhanced weathering effect of lupin as a green manure nay have been the decomposing plant material enhancing the consequent generation of H^+ ions, thereby releasing cations from the cation-exchange sites of the soil (Pilbeam and Morley, 2007). As such, the lupin green manure may release more organic acid and organic chelates than biosolids; thus resulting in a release of cations from the overburden primary minerals through weathering. In weathering processes, organic acids in combination with organic chelates form complexes with the mobilised cations which will allow the movement and subsequent release of ions to solution. Furthermore, the outcome of lupin green manure as an effective enhancer of cation exchange capacity was an increased concentration of Ca and K in the shoots. That is lupin green manure as an enhancer of weathering was effective in providing a better growing medium for plants

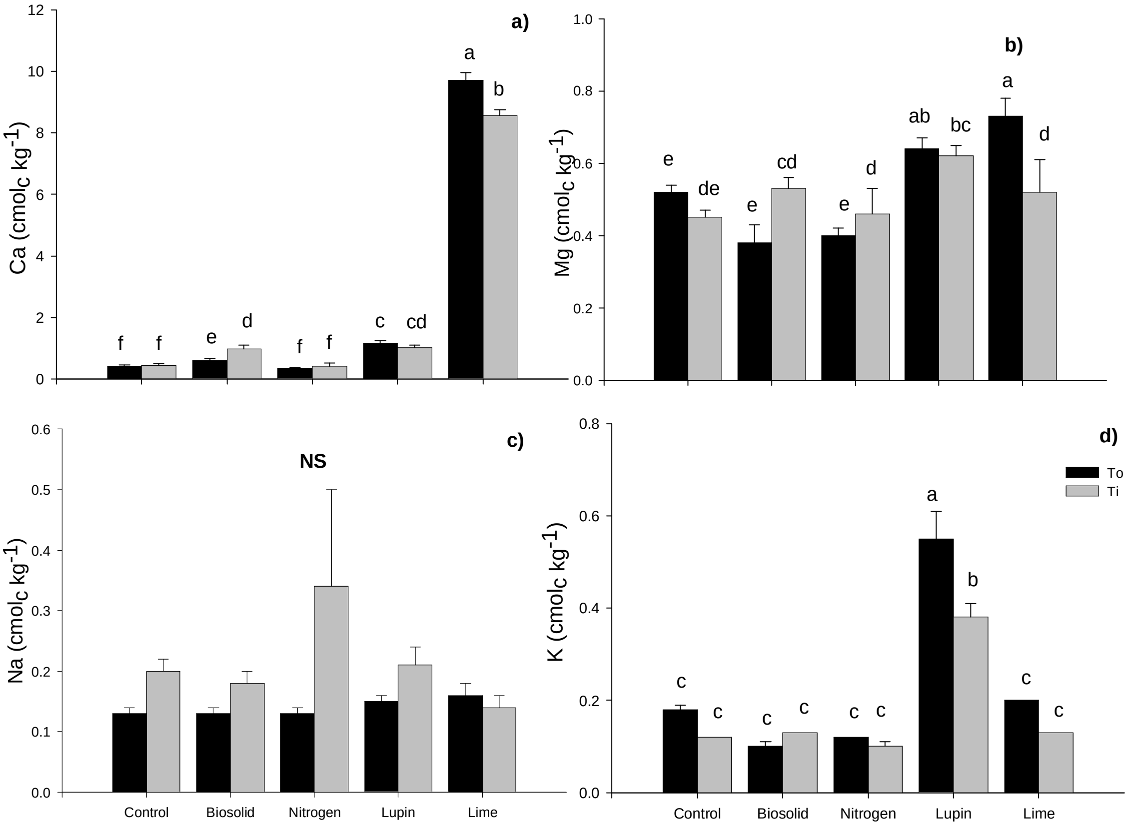

Fig. 1. Exchangeable Ca, Mg, Na and K concentration, before (T_o) and after (T_i) weathering in the overburden collected from Oceana-Gold Globe Progress Mine near Reefton, New Zealand and used in a pot trial with four amendments (biosolids, N, lupin green manure and lime). Means and standard errors are shown (n = 4 for each treatment). Treatments means followed by the same lower case letter were not significantly different at $P<0.05$. There was no significant difference for the overburden exchangeable Na (c) ($P>0.05$).

Heavy metal bioavailability: The results demonstrated that during the weathering processes, the amendments affected the lupin shoot concentration (As, Cu, Mn, Ni, Cd, Pb, Zn and Fe). Application of lupin as a green manure increased the concentration of shoot As, Fe, and reduced the shoot Cd, Cu, Ni, Zn, and Mn. In their study of soil metal immobilisation, Nwachukwu and Pulford (2009) demonstrated that chemical amendments can reduce the solubility of heavy metals by precipitation, while organic amendments reduces the solubility of heavy metals by sorption and chelation of the heavy metals. While these findings agree with the results reported here, organic amendments are also able to promote metal mobility if the metal complexes are formed with amendments are more soluble than the initial status of the metal.

Geochemistry: The results discussed in this section are supported by the geochemistry of the overburden after weathering (T_i). The organic amendments (biosolid and lupin green manure) increased the value of Fe_p (Fe from pyrophosphate extraction) more than the inorganic amendments (N and lime), with lupin increasing the Fe_p value the most. It is likely that the addition of lupin increased the release of Fe from the organic complexes in the overburden which readily reacted with organic acids from the lupin green manure, thus increasing the rate of weathering processes. The high percentage of organically-bound Fe in the overburden at T_i indicates that the weathered overburden contained high amounts of Fe-humus complexes (data not presented). A combination of low pH of the overburden (data not presented) and high concentration of Fe-humus complexes is likely to have resulted in the high solubility of Fe which may speed up weathering processes. It is likely that the decomposition of lupin as a green manure increased the concentration of Fe-humus complexes in the overburden. In addition, after the weathering period (T_i) in the lupin treatments the concentration of ferrihydrite increased in the overburden. The presence of ferrihydrite in soils is an indication that the soil has a large surface area and reactive surface groups. An increase in the surface area and reactive surface groups would lead to an increase in overburden exchange capacity and the progression of pedogenesis.

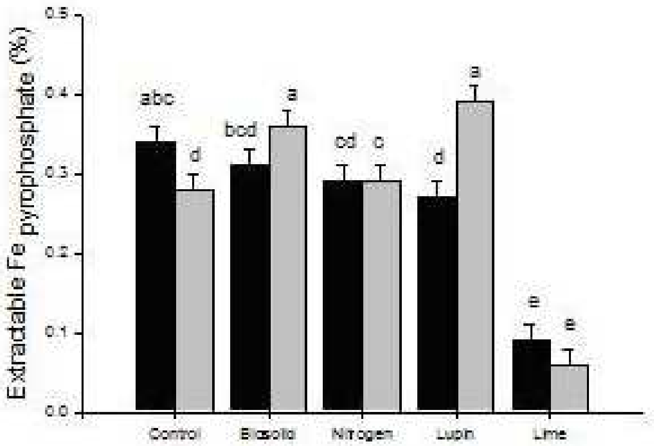

Fig. 2. The pyrophosphate extractable Fe concentration, before (T_o) and after (T_i) weathering in the overburden collected from Oceana-Gold Globe Progress Mine near Reefton, New Zealand and used in a pot trial with four amendments (biosolid, N, lupin and lime). Means and standard errors are shown (n = 4 for each treatment). Treatments means followed by the same lower case letter were not significantly different at $P<0.05$.

Conclusions

This study found that inorganic amendments were less effective than organic amendments for augmenting weathering processes. Among the amendments tested, lupin as a green manure effectively improved the nutritional status of the overburden by increasing the cation concentration, the Fe present in humus-complexes and the amount of ferrihydrite present in the overburden.

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