TECHNOSOL EVALUATION FOR MINE SITE RECLAMATION ON THE BOREAL SHIELD

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Abstract

The application of Technosols manufactured from industrial waste materials for use in mine reclamation is of interest due to the lower associated environmental and economic costs. Long-term studies of the development of Technosols will provide information on how the changing soil conditions will affect plant survival and growth, information critical for determination of their utility as a site reclamation material. The ability of Technosols to support the growth of vegetation on gold mine sites on the Canadian Shield is being examined in order to determine if they provide a viable reclamation option following mine closure. Technosols were manufactured from crushed mine rock and woody residuals in fixed ratios (60:40 and 20:80) and placed on the surface of mine rock lysimeters at 30 cm or 60 cm depths. Soil microclimate data at various depths was monitored from late 2012 to 2015 and compared with microclimate data from both more traditional reclamation materials, and also from a nearby natural pedon. Technosol pore-water chemical composition and physical changes observed over the same period are also highlighted in this study.

Introduction

Site reclamation, a key component in mine closure plans, requires research into cost-effective reclamation methods beneficial to both the mining industry and the post-mining environment. Mining, particularly surface mining, severely disturbs areas by removing vegetation, topsoil, and geological materials (Turcotte, Quideau, & Oh, 2009); this effectively returns the land to a state for primary successional processes to operate (MacKenzie & Quideau, 2010). Reclamation of these sites therefore requires the addition of soil material to the site (Macdonald et al., 2015).

Soil materials which are commonly added to sites as part of reclamation efforts include stockpiled soils removed during mine construction (Gaster, Karst, & Landhäusser, 2015; Sorenson, Quideau, MacKenzie, Landhäusser, & Oh, 2011), as well as soils constructed from a combination of stockpiled overburden materials and organic materials such as peat (MacKenzie & Quideau, 2010). These soils often have unusual physical and chemical properties as a result of their human origin, and follow development trajectories which differ from those of natural soils (Leguédois et al., 2016). They are classified as Technosols by the World Reference Base for Soil Resources due to the strong influence human activities have had on their formation (IUSS Working Group WRB, 2014).

Manufacturing a soil for mine reclamation from local industrial waste materials such as mine overburden or lumber mill residuals could have considerable environmental and economic benefits. The necessity of transporting large volumes of soil material from other locations is removed, providing cost savings, reducing greenhouse gas emissions, and preventing the disturbance of soil source sites. Technosol manufacture also provides a use for waste products which otherwise would be valueless. Long-term studies of the development of Technosols are necessary to understand how changing soil conditions will affect plant survival and growth, which will determine their utility as a reclamation material.

Previous research into the use of a Technosol to revegetate a non-acid generating rock pile from a gold mine in the Boreal Shield found that crushed mine rock blended with woody residuals from a lumber mill was able to support vegetation such as green alder (*Alnus viridis*) even at early stages in soil development (Watkinson, 2014). Further study into the changes in soil properties and their ability to support larger and more diverse communities of native Boreal vegetation as the Technosol matures will provide increasing insight into the use of Technosols created for mine reclamation.

Methods

Research is being conducted at Barrick-Hemlo (Williams Mine) in Hemlo ON, north of Lake Superior. The combination of an open pit and underground workings has generated a large rock pile which will need to be revegetated upon mine closure. The mine rock is predominantly metasedimentary and intermediate volcanic rock and is non-acid generating; therefore it was determined to be a suitable mineral component for the formation of a Technosol to reclaim the rock pile. The woody residuals organic component of the Technosol consists of sawdust, bark, and off-cuttings of boreal coniferous trees from a lumber mill located about 40 min away in White River.

In the summer of 2012, two Technosols were manufactured from the crushed mine rock and woody residuals in fixed ratios (60:40 and 20:80) to obtain low organic and high organic materials. They were placed on the surface of mine rock lysimeters at 30 cm or 60 cm depths. Each soil-depth combination was replicated four times for a total of twelve plots.

Within each plot 5TM soil temperature/moisture sensors were installed at 10, 30, and, where applicable, 60 cm (Figure 1). Additional sensors were installed at 5 cm July 2014. Each plot also contains one MPS-2 water dielectric potential/temperature sensor at 30 or 60 cm. In July 2014 sensors were installed in the same manner in the successional field behind the plots, an area reclaimed using traditional methods, and in a nearby forest site. These sensors allow the Technosol microclimate to be compared to that of more natural regional soils.

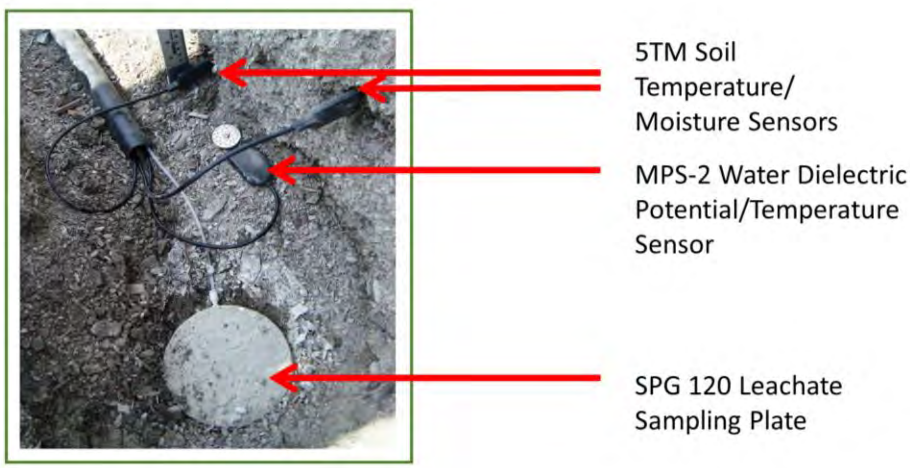

Figure 1. Position of sensors within the Technosol profile. 5TM sensors are located at 5, 10, 30, and (where applicable) 60 cm; MPS-2 sensors and leachate sampling plates are located at base of Technosol layer (30 or 60 cm).

The base of the lysimeters is connected to a large barrel through a drainage tube attached to the geomembrane, allowing the collection of water which has percolated through both the Technosol and mine rock layers (gravity through-flow, Figure 2). There is also a soil leachate sampling plate made of porous borosilicate glass installed in each lysimeter approximately 5 cm above the Technosol/mine rock interface to sample plant root available water held in the Technosol (tension water; Figure 1). These plates draw in water under low vacuum, being pressurized to -0.5 bar with a hand pump to obtain samples. The sample collected represents water held in the soil between field capacity and plant wilting points which is available to plant roots. The water samples are analyzed for pH, EC, Eh, dissolved organic carbon (DOC), anions, and other elements. Uncovered mine rock test cells operated by the mine are also monitored provide information on the natural biogeochemical weathering release from the rocks to percolating waters through time.

Figure 2. Barrel connected to base of Technosol lysimeter for collection of gravity through-flow water.

Green alders (*Alnus viridis*), a native species, were planted in summer 2013 and again in summer 2015 to ensure each plot contained nine plants. Bearberry (*Arctostaphylos uva-ursi*) was also planted in summer 2015, at twelve plants per plot.

Results and Discussion

Temperature data from the end of June 2014 to mid-October 2015 shows large differences in the 10 cm soil temperature variation in the Technosol plots compared to the natural forest soil (Figure 3.) The Technosol plots appear to have more variable temperatures at 10 cm that are closer to the extremes in air temperature than the forest soil. This is particularly noticeable in the winter, where the Technosols drop well below 0°C in late November and remain there until May; in contrast, the temperature in the forest soil remains around 0°C throughout the winter months. Some of the difference in winter temperature may be attributable to the exposure of the Technosol plots, which may prevent the building up of the deeper snow pack which insulates the forest soil. However, as the rock pile itself is also highly exposed, the conditions of the plots are a more accurate simulation of conditions on the pile than the observed adjacent forest soil.

There is also a clear difference between the Technosols and forest soil temperature during summer, particularly in the low-organic Technosol plot where soil temperatures reach air temperature. The temperature at 10 cm in the high organic Technosol, though not as extreme or variable, is still noticeably warmer than the forest soil from the end of May throughout the summer. Again, the exposure of the plots to sun and wind likely contributes to the higher temperatures than those observed in the forest soil pedon. The difference between the high and low organic Technosols may be due to the increased moisture holding capacity of the high organic Technosol.

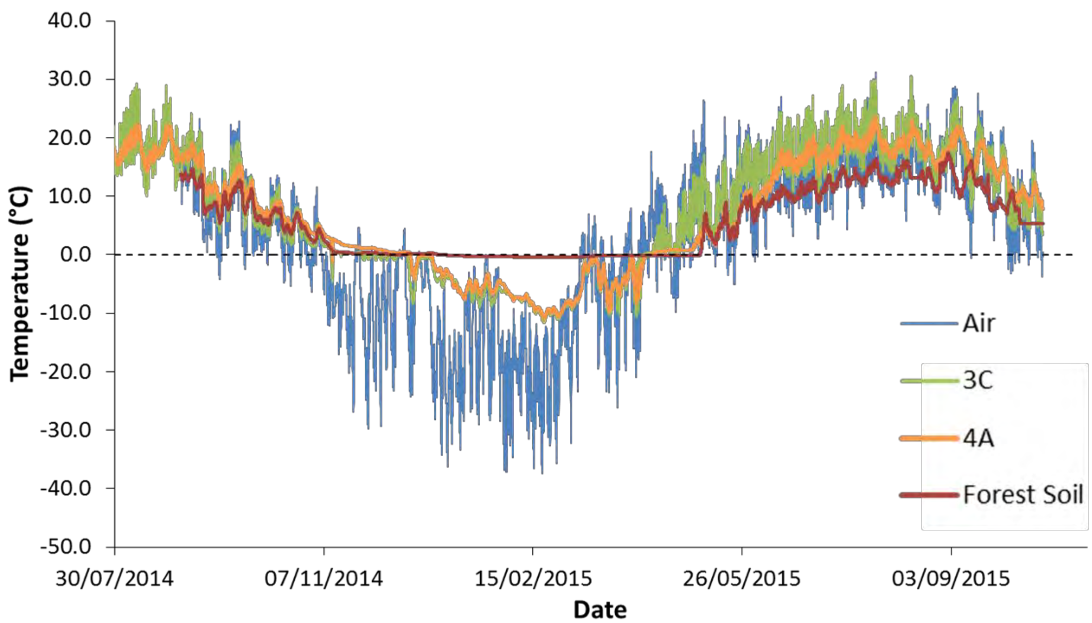

Figure 3. Temperature at 10 cm depth in low (3C) and high (4A) organic Technosol plots and forest soil (June 2014 – Oct 2015). Air temperature at 3 m is also displayed.

The pH of gravity through-flow samples from the Technosol plots from Oct 2012 to Oct 2015 indicates that the water percolating through the Technosol has remained close to neutral (Figure 4) throughout the three-year measurement period. No pH differences between the Technosol treatments were seen. There were also no differences between the tension water and gravity through-flow samples. On average, Technosol waters were slightly more acidic than samples coming from the uncovered mine rock test cells during the same period. The Technosol water samples have a similar pH to the natural waters within the region. These values are likely buffered by the carbonate minerals present within the rock.

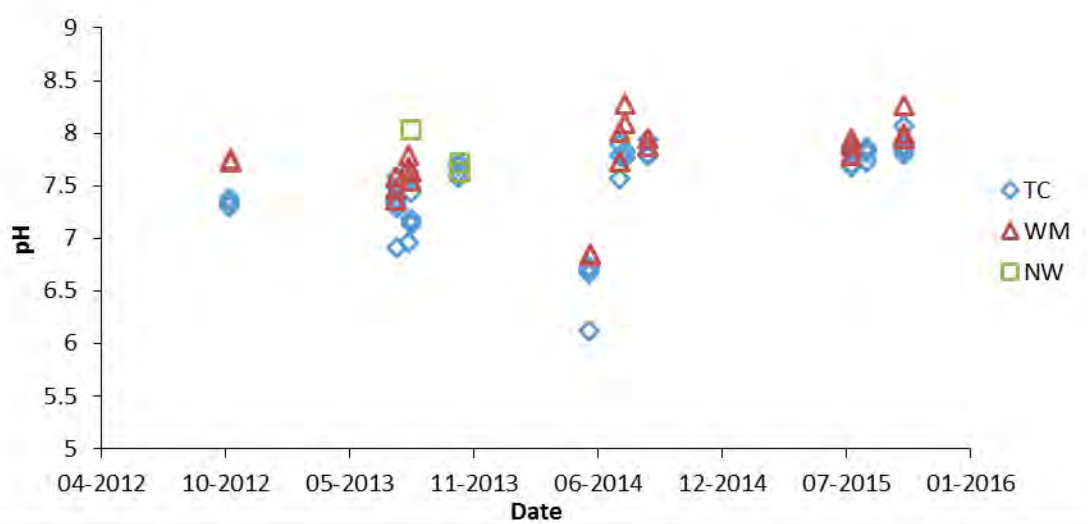

Figure 4. pH of gravity through-flow from Technosol plots (TC), mine rock test cells (MR), and natural waters (NW) from Oct 2012 to Oct 2015.

While there was little difference between the pH of the uncovered test cells and the Technosol plots, there is a clear difference in electrical conductivity (Figure 5), which is a proxy for the total dissolved ions present in the water. The gravity through-flow samples from the Technosol plots clearly have a higher conductivity than the uncovered mine rock plots and natural waters in the region, and this difference appears to be more pronounced with time. Some of the observed differences could be due to the fact that the mine rock in the Technosols is crushed to more surface reactive gravel size, much finer than the rock used in the mine rock test cells. Dissolved substances released from the organic material may also be contributing to greater biogeochemical weathering in the Technosol plots than the mine rock test cells.

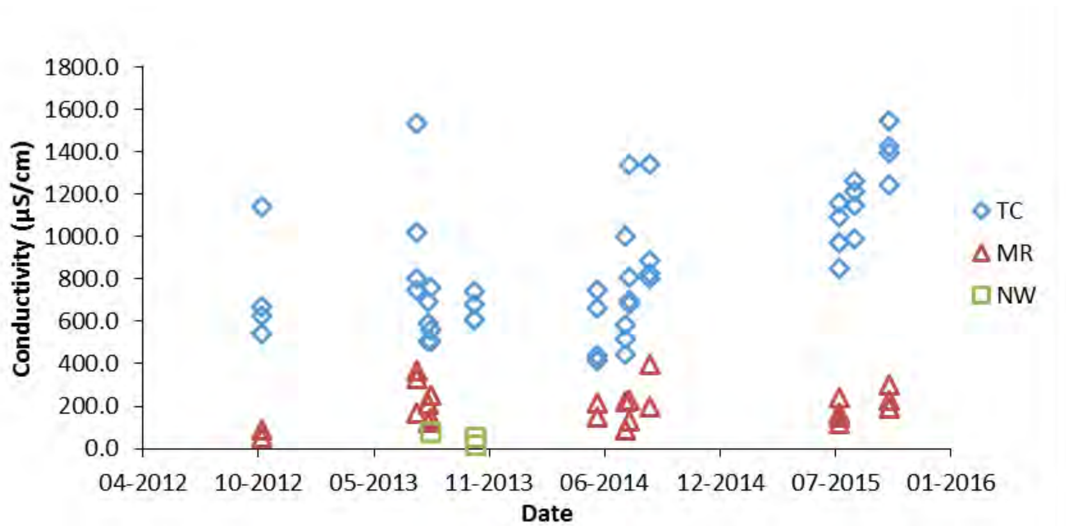

Figure 5. Conductivity (µS/cm) of gravity through-flow from Technosol plots (TC), mine rock test cells (MR), and natural waters (NW) from Oct 2012 to Oct 2015.

The behaviour of select elements within the gravity through-flow and tension water samples from the Technosol plots has been compared to those in the uncovered mine rock test cells. The concentrations of calcium and magnesium divalent cations within Technosol gravity through-flow and tension water samples are consistent higher than concentrations within water samples from the uncovered mine rock plots (Figure 6). Calcium concentration in gravity through-flow is noticeably greater than concentrations in tension water, particularly in 2015. Magnesium concentrations also appear to be greater in gravity through-flow samples, although the pattern is less clear. Samples from the 60 cm low-organic Technosol plots typically have the highest concentrations for both elements, and remain relatively consistent from 2013 to 2015.

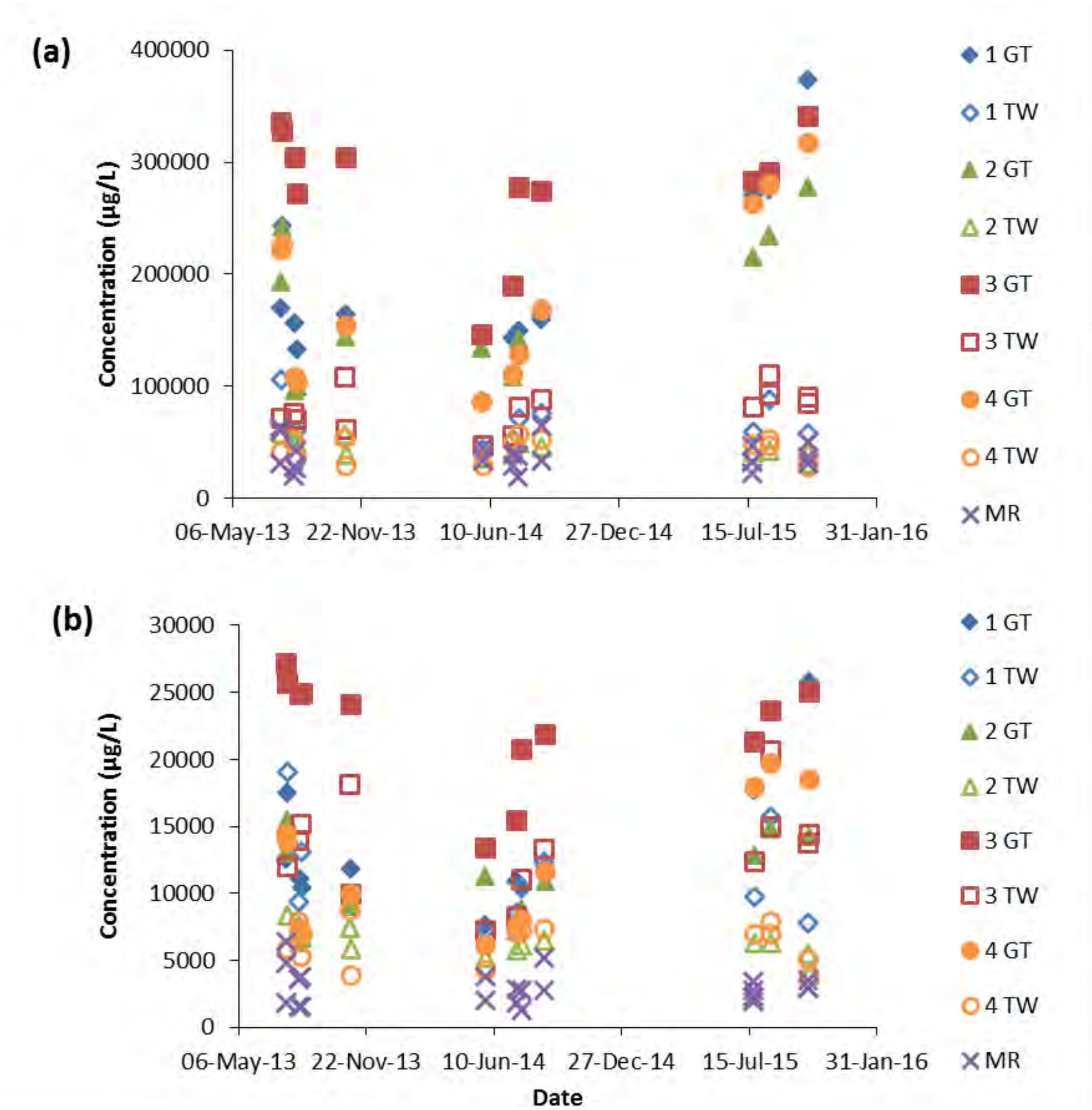

Figure 6. Concentrations of (a) Ca and (b) Mg in Technosol gravity through-flow (GT, solid fill), tension water (TW, hollow), and mine rock test cell (MR) water samples. Treatments are 1: 40% organic, 30 cm; 2: 80% organic, 30 cm; 3: 40% organic, 60 cm; 4: 80%, 60 cm.

The redox-sensitive elements iron and manganese show a similar trend in decreasing concentrations from 2013 to 2015 (Figure 7). Initially the concentrations of both elements in gravity through-flow samples from the Technosol plots were much higher than concentrations in water samples from the uncovered mine rock test cells, while tension water samples had lower concentrations more similar to the mine rock test cell samples. However, there appears to be an exponential decrease in concentration, particularly in iron. By 2015 there is no difference in concentrations of iron and manganese between Technosol gravity through-flow, tension water, or mine rock test cell samples.

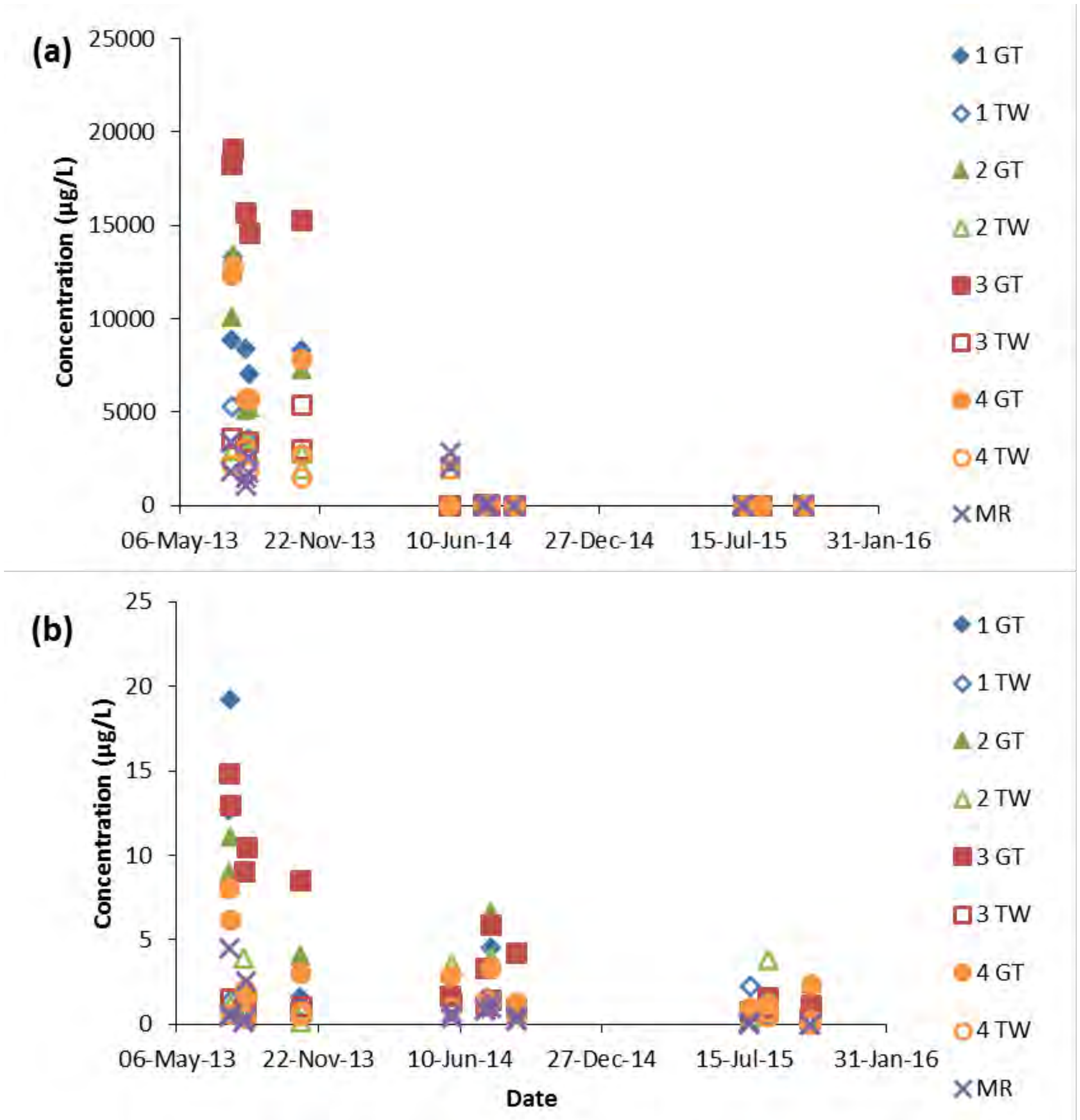

Figure 7. Concentrations of (a) Fe and (b) Mn in Technosol gravity through-flow (GT, solid fill), tension water (TW, hollow), and mine rock test cell (MR) water samples. Treatments are 1: 40% organic, 30 cm; 2: 80% organic, 30 cm; 3: 40% organic, 60 cm; 4: 80%, 60 cm.

The behaviour of copper, an important trace nutrient, and cadmium, an element of environmental concern, within the water samples were very different. Cu shows no trend as the Technosol matures, with no clear difference in concentrations in gravity through-flow and tension water (Figure 8a). However, more copper appears to be released from the Technosol plots than from the mine rock test cells.

There is a clear trend in cadmium concentration of increasing with time (Figure 8b), with gravity through-flow samples having higher cadmium concentrations than tension water samples. This suggests cadmium is more likely to be released into the environment than to be held in the water in the Technosol. Mine rock test cell water samples had highly variable concentrations of Cd, with the cells containing intermediate volcanics and quartz eye muscovite schist having much greater concentrations than in any of the

Technosol plots. Samples of percolating waters from other rock types were comparable to the Technosols (data not shown).

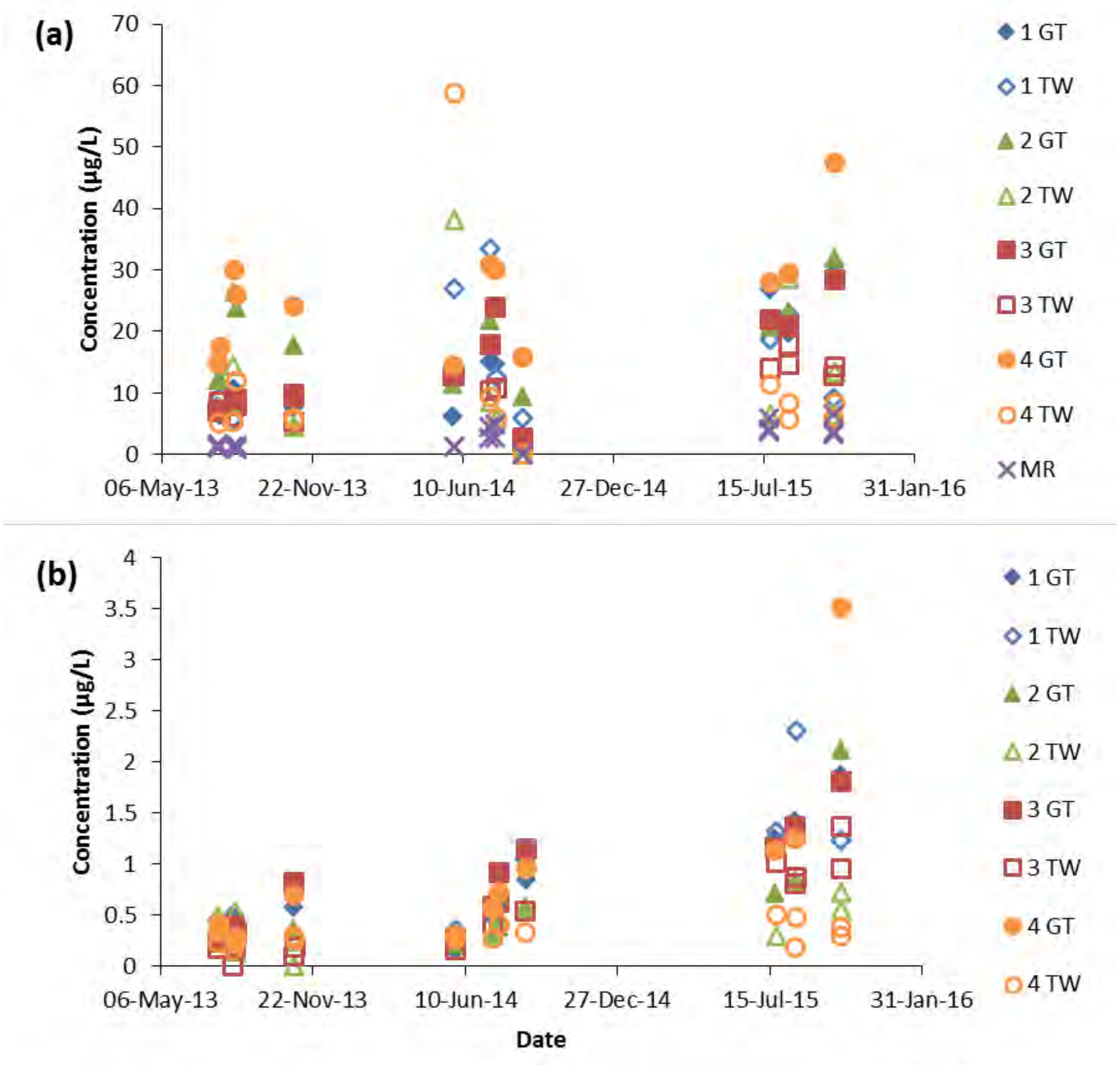

Figure 8. Concentrations of (a) Cu and (b) Cd in Technosol gravity through-flow (GT, solid fill), tension water (TW, hollow), and mine rock test cell (MR) water samples. Treatments are 1: 40% organic, 30 cm; 2: 80% organic, 30 cm; 3: 40% organic, 60 cm; 4: 80%, 60 cm.

Concentrations of molybdenum and phosphorus, both oxyanions, in water samples also showed very different trends (Figure 9). Molybdenum concentrations are generally higher in gravity through-flow samples than in tension water, while there are no clear differences observed for phosphorus. Phosphorus concentrations decrease with time, while molybdenum concentrations remain fairly constant. Phosphorus concentrations in Technosol plots are generally higher than in the uncovered mine rock test cells. Molybdenum has a similar pattern to Cd in terms of differences between the Technosols and the mine rock; lysimeters containing intermediate volcanics and quartz eye muscovite schist have much greater molybdenum concentrations than any of the Technosol plots while other rock types display comparable levels over time.

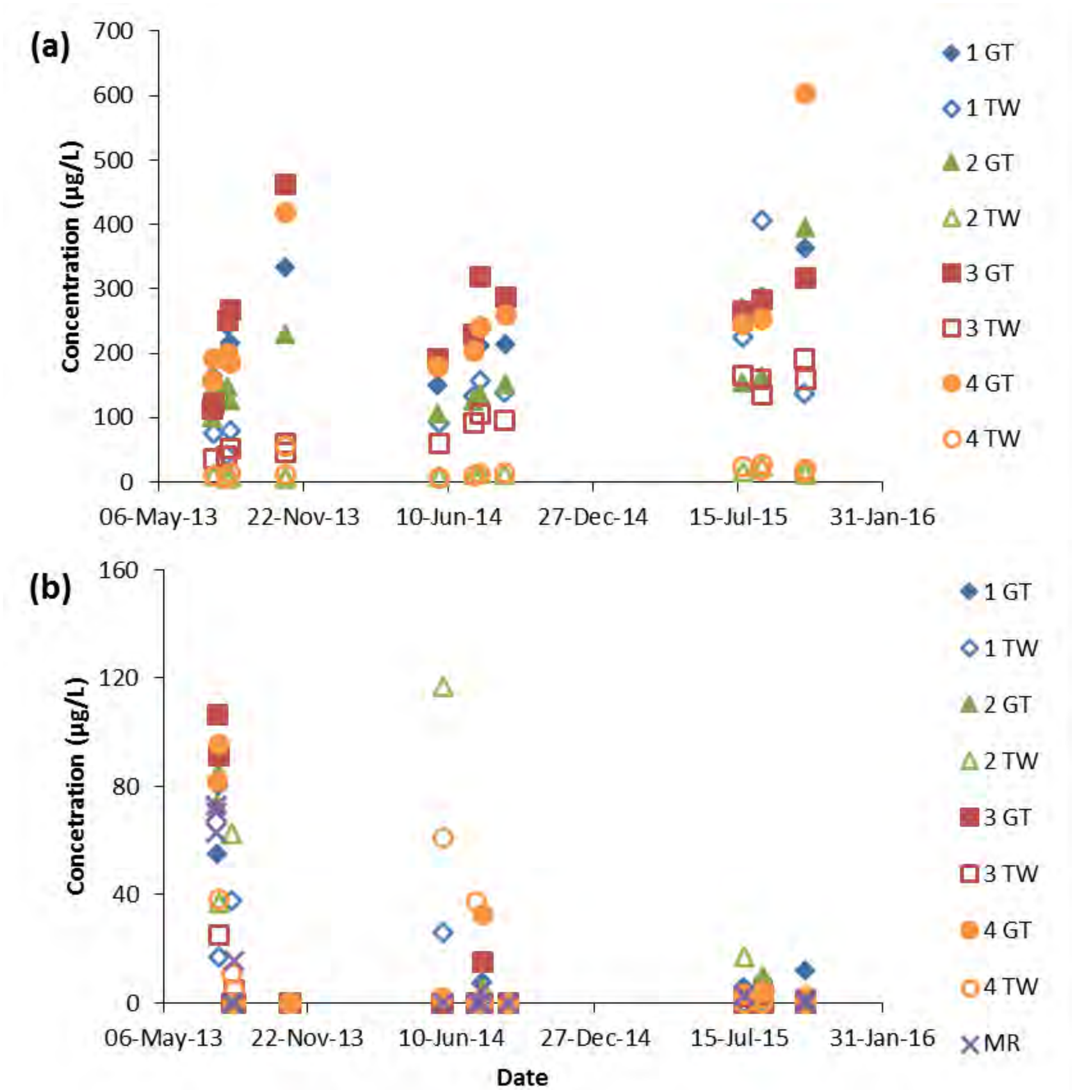

Figure 9. Concentrations of (a) Mo and (b) P in Technosol gravity through-flow (GT, solid fill), tension water (TW, hollow), and mine rock test cell (MR) water samples. Treatments are 1: 40% organic, 30 cm; 2: 80% organic, 30 cm; 3: 40% organic, 60 cm; 4: 80%, 60 cm.

Conclusion

The temperature at 10 cm depth in the Technosol plots was noticeably more variable than in a natural forest soil, displaying greater extremes in both summer and winter. There were no differences between the pH of the Technosol, uncovered mine rock, and natural water samples, although there was a clear increase in Eh in the Technosol samples. Comparison of element concentrations in the Technosol and mine rock water samples revealed the addition of the organic matter increased the concentration of calcium, magnesium, and copper, while decreasing trends were seen for iron, manganese, and phosphorus concentrations, and an increasing trend was seen in cadmium.

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