CLOSING THE LOOP: BIOSOLIDS TO REBUILD DEGRADED SOILS

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Abstract
Biosolids represent a valuable source of soil nutrients and zinc, a trace element that is deficient in many areas. Yet environmental concerns, particularly regarding nitrate leaching, limit the application of biosolids to soil. Biochar, a form of charcoal that is added to soil, is a potential solution. We aimed to determine the effect of biosolids and biochar addition to the uptake of Zn by crop plants and investigate the effects of biochar addition on Zn uptake and nitrate leaching from biosolids amended soil. We tested 10 common crop plants as well as pasture in a pot trial with and without the addition of biosolids and biochar. The effect of biochar on the nitrate leaching from biosolids amended soil was measured in a lysimeter experiment. There were large species differences in Zn uptake from the biosolids and biochar amended soils. Beetroot (*Beta vulgaris*) and spinach (*Spinacia oleracea*) showed the greatest increases are good candidates for further biofortification research. Over a five-month period, biochar reduced the nitrate leaching from a biosolids amended soil to levels below an unamended soil. Future work will focus on the performance of the system over the long-term.

Introduction
Countries with sewage treatment plants produce some 27 kg of dry biosolids per person per year (Bradley, 2008). Biosolids represent a valuable source of soil nutrients, including phosphorus, of which global supplies are dwindling. Their addition to soil can improve fertility and store carbon that may otherwise be emitted into the atmosphere and exacerbate climate change. However, biosolids contain heavy metal and organic contaminants as well as pathogens. Prolonged addition of biosolids to soil may result in the accumulation of these contaminants to levels that pose a risk to human health and the environment. Therefore, their addition to fertile productive lands is not widely accepted.

We propound that biosolids be applied to degraded soils with the aim of restoring fertility and producing products that contain high concentrations of the essential micronutrients zinc and copper. Zinc and copper are the two most prevalent heavy metals in biosolids are Zn and Cu. Worldwide, some 35% of children and 20% of adults suffer from Zn deficiency (White and Broadley, 2005). Biosolids addition to soil may thus be a means of producing crops that are "biofortified" with these elements. Biosolids addition to degraded soil represents a closing of the loop, returning nutrients that have been removed in through degradation.

Unlike using biosolids as a fertiliser on productive soils, rebuilding degraded soils requires biosolids addition at a relatively high rate. This is because the role of the biosolids is to provide soil organic matter, rather than solely supplying nutrients. However, high application rates may result in excessive nitrate leaching and subsequent groundwater contamination or eutrophication of nearby lakes and rivers.

We hypothesised that some of the negative environmental effects associated with biosolids addition to soil could be mitigated by mixing the biosolids with biochar, a form of charcoal that is added to soil (Lehmann and Joseph, 2009) often with the goal of reducing impacts of greenhouse gas emissions (Clough & Condron, 2010). Biochar can improve porosity, surface area, and structure. Chemically, biochar may mitigate contaminants of biosolids through increased cation and anion exchange capacity, as well as increase soil pH. Soil microbes may also benefit from applications of biochar (Clough & Condron, 2010).

We aimed to determine the effect of biosolids and biochar addition to the uptake of Zn by crop plants and investigate the effects of biochar addition on Zinc uptake and nitrate leaching from biosolids amended soil. Here, we present the results of experiments that demonstrate that soils amended with both biosolids and biochar produce biofortified crops while avoiding excessive nitrate leaching.

Materials and methods

Experiment 1

Biosolids (pH=5.4, Zn = 877 mg/kg, N = 2.7%) were sourced from the Kaikoura sewage treatment plant. Biochar was produced from untreated *Pinus radiata* off cuts as described in Taghizadeh-Toosi et al. (2011). Four soil mixtures were prepared using a Canterbury fine sandy loam (pH = 5.7, Zn = 54 mg/kg, N=0.2%) with 4% (w/w) biosolids addition, 4% (w/w) biochar addition, and 4% biosolids + 4% biochar. Into each treatment, five replicates were planted of beetroot (*Beta vulgaris*), broccoli (*Brassica oleracea*), carrot (*Dacus carota*), leek (*Allium ampeloprsum* var *porrum*), lettuce (*Latuca sativa*), radish (*Raphanus sativus*), Corn (*Zea mays* var *rugosa*), spinach (*Spinacia oleracea*) tomato (*Solanum lycopersicum*), courgette (*Curcubita pepo*), and perennial ryegrass (*Lolium perenne*). Plants were grown in 2 l pots (except corn in 15 litre pots) in a greenhouse at Lincoln University, New Zealand, and harvested when mature. After weighing the dried shoots, the edible / forgeable portions were excised, weighed, and analysed using ICP-OES.

Experiment 2

Twelve lysimeters (50 cm diameter x 78 cm deep) were prepared using an intact core of a Canterbury fine sandy loam with the above-described treatments added to biosolids addition equivalent to 0, and 600 kg N per hectare and biochar addition equivalent to 0 and 100 tonnes per hectare. Perennial ryegrass (*Lolium perenne*) was grown on all lysimeters. Leachates were collected fortnightly from May – October 2010 and analysed for nitrogen species and trace elements.

Results

The addition of biosolids and biochar resulted in a significant increase in the growth (data not shown) and Zn concentrations in most, but not all, of the plants tested (Fig. 1) compared to the control. The biofortification factor (treatment / control concentration quotient) ranged from 0.7 (corn) to 6.7 in the beetroot leaves, which are used in salads and could be used for stock fodder. The addition of biosolids alone (data not shown) also resulted in increased Zn concentrations, which often significantly different from the biosolids + biochar treatment. In most cases, the Zn concentrations in the biochar (no biosolids) treatment were lower than the controls. The concentrations of other trace elements were significantly affected by the treatments.

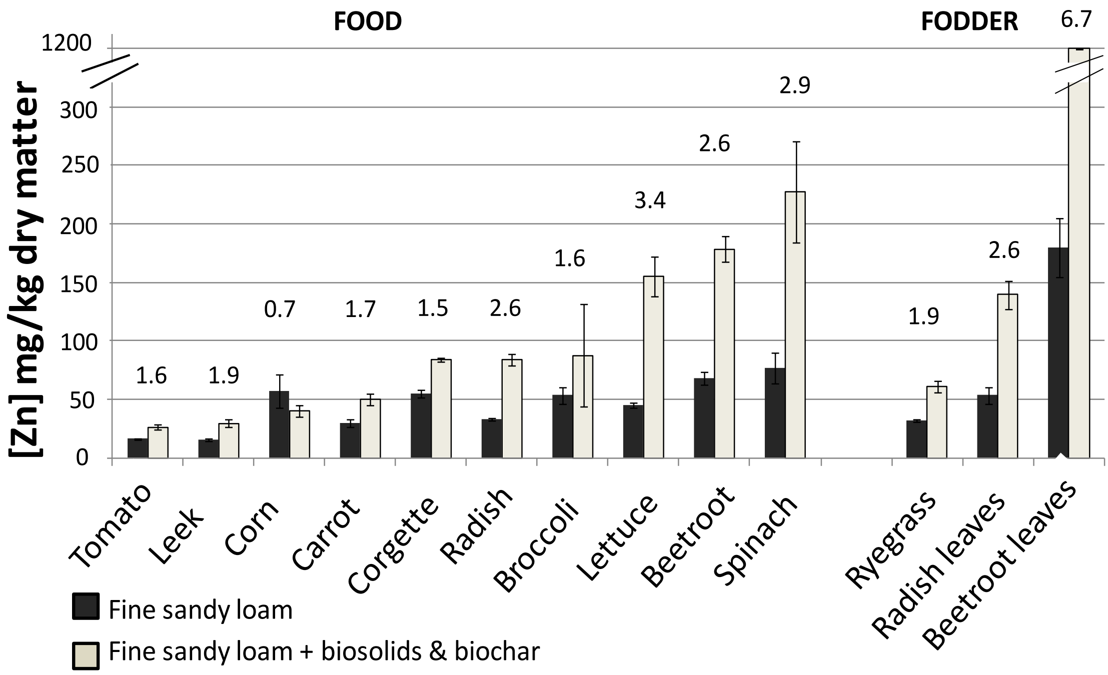

Figure 1. Zinc concentrations (mg/kg) in the edible (food) or forgeable (fodder) portions of the plants. The number above the bars is the biofortification factor (treatment / control concentration quotient). Bars represent the standard error of the mean (n=5)

The addition of biosolids equivalent to 600 kg N / ha caused a significant increase in nitrate leaching from the lysimeters (Fig. 2). However, the addition of biosolids + biochar actually resulted in nitrate leaching being reduced to levels below the control, thus indicating that over the short term, biochar can successfully mitigate nitrate leaching from biosolids amended soil.

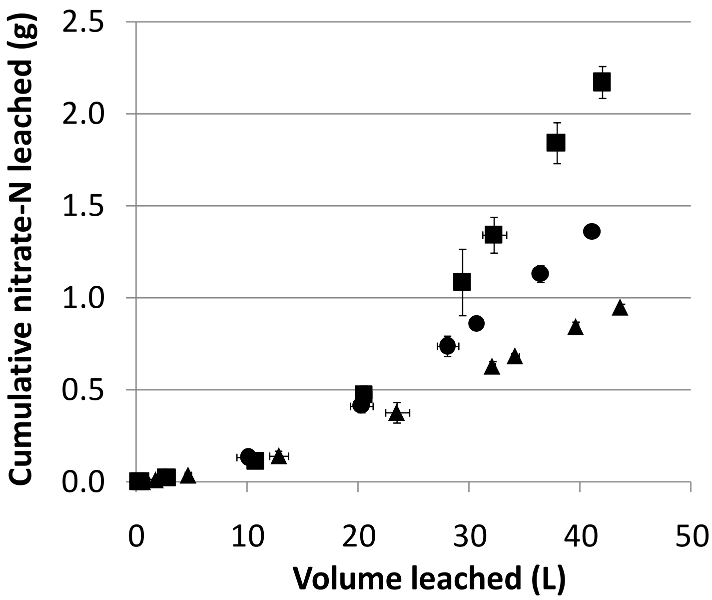

Figure 2. Nitrate (mg/L) in drainage water from the lysimeters with no treatment (circles), biosolids (squares) and biosolids + biochar (triangles). Bars represent the standard error of the mean (n=3)

Discussion

The results of this short-term pot trial and lysimeter experiment do not indicate whether successive crops will be significantly biofortified with Zn. This is the subject of ongoing research.

Biochar could mitigate nitrate leaching from biosolids by inhibiting the mineralisation of organic N to ammonia and thence to nitrate or by sorbing ammonium or nitrate, thus rendering it less available for leaching and plant uptake. If sorbtion was occurring, the mechanisms for this are unclear. The cation exchange capacity of the biochar was less than the soil, indicating that retention of ammonium via this mechanism will not be significant. The anion exchange capacity of the biochar was just 4.0 $cmol_{(+)}$/kg, ruling out significant electrostatic binding of nitrate. Potentially, soil solution containing ammonium and nitrate could have been incorporated into pores on the surface of the biochar. However, such pores would have rapidly become saturated and further mineralised N would have leached. Alternatively, the biochar may have inhibited the growth of soil flora that normally mineralises and nitrifies N. This could have occurred through some toxic agent on the surface of the biochar, or by providing refugia for competing microorganisms or denitrifying bacteria.

We have yet to measure the effect of the treatments on organic contaminants such as endocrine disruptors and triclosan. Similarly the effect of biochar on pathogen survival is unclear.

Future work should focus on modelling the interactions of various biosolids / biochar mixtures on speciation of trace elements and nitrogen in soil solution over the long term.

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