LAND APPLICATION OF MUNICIPAL BIOSOLIDS:

ASSESSMENT OF ECOLOGICAL IMPACTS AND CHARACTERIZATION OF PRIORITY EMERGING SUBSTANCES OF CONCERN

LYNDA H. MCCARTHY, RYERSON UNIVERSITY AND JORGE LOYO, RICE UNIVERSITY

Published August 2016

Canadian Water Network

LAND APPLICATION OF MUNICIPAL BIOSOLIDS:

ASSESSMENT OF ECOLOGICAL IMPACTS AND CHARACTERIZATION OF PRIORITY EMERGING SUBSTANCES OF CONCERN

LYNDA H. MCCARTHY, RYERSON UNIVERSITY AND JORGE LOYO, RICE UNIVERSITY

Published August 2016

WHY DID WE DO THIS RESEARCH?

Biosolids produced during wastewater treatment are predominantly incinerated, landfilled, or applied to land for agricultural or reclamation purposes. Concerns about pathogens and a wide array of chemicals in untreated sludge and biosolids led to the development of regulations governing land application, including limitations to heavy metal disposal in sewer systems, sludge treatment standards, and agricultural management practices. However, as an increasing number of chemicals in biosolids are detected — including the so-called emerging substances of concern (ESOCs), anxieties about the potential risks of biosolids land application to human and environmental health have resurfaced.

Historically, the impact of amending agricultural soils with biosolids has mostly been studied in plants, especially crops. Overall, land-applied biosolids have a positive impact on plant growth and yield, except when extremely high application rates are used (which are currently not permitted by regulations). The majority of studies focused on metals present in biosolids, but few have addressed ESOCs specifically. The few existing studies on the potential impact of biosolids on terrestrial and aquatic organisms predominantly assessed the impact on a single species. These studies often involved application rates or growing conditions that were not environmentally-relevant (for example, hydroponics), or used external additions of ESOCs (spiking experiments), which are known to affect bioavailability.

In addition, formal risk assessments for most ESOCs cannot be formulated due to a lack of toxicity and ecotoxicity data. Typical risk assessments use a chemical-by-chemical approach, which does not account for the effects of simultaneous exposure to mixtures of chemicals or their transformation products. A more holistic perspective is needed to determine whether ESOCs in biosolids pose a risk to human and/or environmental health in the context of agricultural land application. Ideally, this approach would be simple, rapid, and inexpensive and able to anticipate potential ecotoxicity prior to land application.

WHAT DID WE DO?

This 2013-2015 project studied, under controlled laboratory conditions, the potential impact of soil amended with different types of biosolids (produced by anaerobic digestion, alkaline stabilization, composting, and pre-treated using high-pressure thermal hydrolysis) on the growth, behaviour, and/or reproduction of a multi-species array of terrestrial and aquatic organisms (Figure 1). The effects of biosolids on soil-plant relationships were also examined, specifically on the health of arbuscular mycorrhizal (AM) fungi communities.

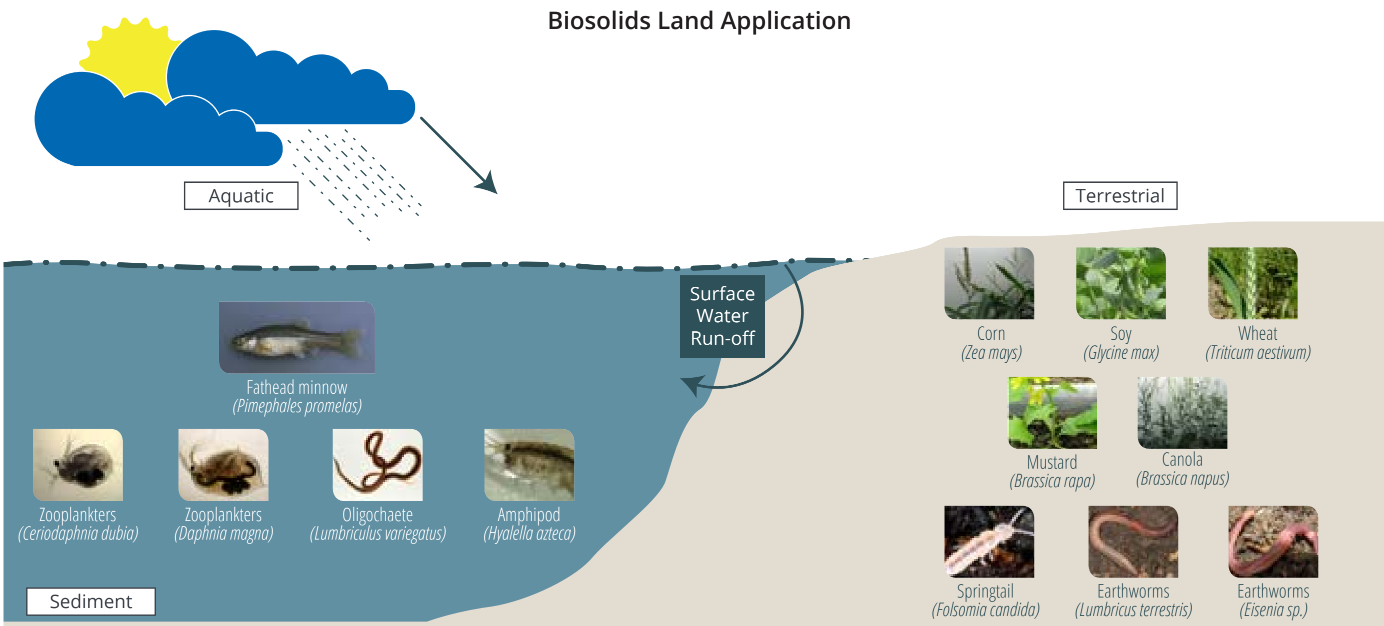

Figure 1. Terrestrial and aquatic organisms studied

The chemical make-up of biosolids was assessed before and after treatment in order to: i) identify the responsible constituents if impact was observed; ii) study uptake and bioaccumulation of ESOCs by plants; and iii) assess if treatment or pre-treatment processes affect ESOCs concentrations in biosolids.

Methodologies for the screening and analyses of a suite of ESOCs in biosolids and biological tissue were developed.

ESOCs analyzed included:

- pharmaceuticals (carbamazepine, trimethoprim, sulfamethoxazole, venlafaxine, desvenlafaxine, citalopram, sertraline, fluoxetine, atenolol, propranolol, metoprolol, sotalol, metformin, ibuprofen, gemfibrozil, acetaminophen, naproxen)
- drug metabolites (*O*-desmethylvenlafaxine, *N*-desmethylvenlafaxine, desmethylcitalopram, desmethylsertraline)
- hormones (estradiol, estrone, ethinylestradiol, androstenedione)
- antibacterials (triclosan, triclocarban)
- synthetic musks (galaxolide, HHCB, and tonalide, AHTN)
- sweetener (sucralose)
- caffeine
- markers of nanomaterials (silver and titanium)
- organic flame retardants (including congeners of PBDEs and congeners of Dechlorane)

To study the effect of sludge treatment (including anaerobic digestion) on both impact to biota and the fate of ESOCs, the biosolids samples in the impact assessment included biosolids produced by different sludge treatment methods such as alkaline stabilization and composting. The effects of high-pressure thermal hydrolysis sludge pre-treatment on the performance of anaerobic digestion and on impact to biota and ESOCs concentrations were also assessed.

WHAT DID WE FIND?

Few negative impacts were noted when organisms were exposed to soils amended with biosolids at agronomically-relevant rates.

PLANTS

Canola, mustard, and corn showed no negative impact from land-applied biosolids and grew better in amended soils, presumably due to the nutrients provided by the biosolids. Plants grown in soils amended with biosolids were either taller and had a larger mass or showed no significant differences to plants grown in reference soil.

The endpoints evaluated for the three species included the percentage of planted seeds that germinated and the time for plant emergence from the soil. For corn, the number of leaves, plant height, and mass (shoot, roots, and ears) were evaluated. For canola and mustard, the stem height and plant mass (shoot, pods, and seeds) were measured. Germination of second-generation mustard seeds from plants grown in soil amended with biosolids was also evaluated.

In general, there was no significant difference in germination and emergence for plants — including second-generation mustard seeds — grown in soil amended with biosolids compared to plants grown in reference soil. Plant experiments with wheat, soy, and corn showed similar results. The only exception was canola, which showed longer emergence times with some of the samples due to changes in reference soil texture, which became "stickier" after amendment with biosolids.

Biosolids enrichment with triclosan at environmentally-relevant concentrations caused no adverse effects on the plant health endpoints and did not adversely affect colonization of the root tissues of matured plants with arbuscular mycorrhizal (AM) fungi.

The effect of high-pressure thermal pre-treatment on digestibility of thickened activated sludge and primary sludge in two-stage anaerobic digestion and the effect of this treatment on biological impact were similar to the results described above. There was no significant difference in germination percentage and emergence for plants grown in amended soil versus reference soil, although a delay in emergence was sometimes observed due to changes in soil texture after amendment. Plants grown in amended soils were taller and larger or showed no significant differences to the plants grown in reference soil.

TERRESTRIAL ORGANISMS

The avoidance behaviour of two species of earthworms (*Lumbricus terrestris* and *Eisenia* sp.) was evaluated for all biosolids samples. The earthworms were placed in containers filled with 50% biosolids-amended soil and 50% reference soil and their position was recorded after 72 hours. In general, *L. terrestris* showed a preference for the reference soil, while *Eisenia* sp. favoured the soils amended with biosolids.

Given the habitats and behavioural characteristics of each species, this result was expected. *L. terrestris* prefers grasslands, orchards, and arable soil and have a limited tolerance for ammonia (which can be produced in soils amended with biosolids). *Eisenia* prefer damp soil with high organic content, can tolerate low levels of ammonia, and feed on coarse particulate organic matter. The additional organic matter provided by the biosolids may represent a food source for *Eisenia*.

Similarly, in samples with high-pressure thermal pre-treatment of biosolids, *L. terrestris* showed a preference for the reference soil, while *Eisenia* sp. greatly favoured the biosolids-amended soils.

Springtails (*Folsomia candida*) did not show a preference for reference or biosolids-amended soils and were evenly distributed. This may be because springtails have been reported to be less sensitive to soil properties (organic matter and texture) than earthworms. Because springtails prefer fungi on leaf litter to fungi in soil, biosolids do not represent an additional source of food.

Springtail survival was not statistically different between soils amended with biosolids and reference soil for all of the samples in 28-day exposure tests. Springtails (*F. candida*) showed no preference for soil amended with pre-treated biosolids. Survival and juvenile production in biosolids-amended soils were similar to those in reference soil.

AQUATIC ORGANISMS

The aquatic organisms were exposed to laboratory tests simulating tile drainage and surface runoff from modelled heavy precipitation events in troughs modelling field plots with biosolids-amended soil. The event represented a 1-in-100 year storm, and the organisms (with the exception of *Ceriodaphnia dubia*) were exposed to undiluted drainage samples. These conditions were meant to represent a worst-case scenario.

The water column zooplankter *Daphnia magna* and the benthic invertebrates *Lumbriculus variegatus* and *Hyalella azteca* showed little to no 96-hour acute lethality when exposed to either reference or amended samples. *Ceriodaphnia dubia* showed decreased reproduction when exposed to some of the runoff and tile drainage samples due to the presence of high concentrations of ammonia.

Pimephales promelas or fathead minnows were affected by the high concentrations of ammonia — with the exception of the composted biosolids, which produced ammonia levels similar to reference samples and produced no mortality. After 7 days, the larval minnows in reference and compost samples were not significantly different in weight compared to those in reference conditions, indicating no growth impairment (a measure of sub-lethal toxicity).

CHEMICAL ANALYSIS

Most of the ESOCs analyzed (29 out of 31) were present in the biosolids samples studied and the majority of the ESOCs (23) were found in concentrations above the quantification limits. Titanium and silver were present in the highest concentrations, followed by the synthetic musks (HHCB and AHTN) and the antimicrobials (triclosan and triclocarban). The concentrations were within the ranges commonly found in North American biosolids.

The concentrations of the target pharmaceuticals and personal care products were below the limits of detection in corn and canola shoots and husks and there were no differences in the concentrations of total silver and titanium between the experimental and control treatments. This confirms previous findings suggesting that low (if any) accumulation is to be expected in experiments where the target compounds are not spiked into soil.

Ten of the 17 flame retardants analyzed were detected in the biosolids samples in concentrations either comparable or slightly lower than those previously reported in biosolids collected from North America and Europe.

WHAT DO THESE FINDINGS MEAN FOR GENERATORS, REGULATORS, AND OTHER USERS?

Overall, there is little evidence of negative impact to organisms when municipal biosolids are used to amend soil at appropriate application rates.

Plants grown in soil amended with biosolids showed similar or improved germination and growth parameters compared to plants grown in reference soil. Chemical analysis showed little evidence of accumulation of ESOCs in plant tissues.

Terrestrial and aquatic organisms exposed to simulated runoff and tile drainage from biosolids-amended soil were not affected, with the exception of two species. These organisms were negatively impacted by the high levels of ammonia and turbidity in the runoff and drainage samples. However, these conditions simulated a worse-case scenario with excessive biosolids runoff and little dilution, which are unlikely to occur in real-world conditions.

Although the results of this work add to the body of evidence in the scientific literature suggesting that the use of municipal biosolids as agricultural soil amendment is an ecologically-sustainable practice when done according to regulations, some questions remain unanswered. For example, the detailed mechanisms of uptake (or lack thereof, as found in this study) of organic chemicals by plants is not fully understood, although it is expected to be negligible in agricultural settings (i.e., in the presence of soil that binds the chemicals) when organic chemicals are introduced as part of the biosolids and not added separately, such as in pesticides.

Further field study — including a thorough whole-organism ecosystem evaluation — should be conducted to better explore the possible impacts of biosolids land application at the ecosystem level to understand whether biosolids in general, and ESOCs in particular, are having an impact on ecosystems.

TO CONTACT THE RESEARCHER, EMAIL RESEARCHSPOTLIGHT@CWN-RCE.CA.
VISIT OUR REPORT LIBRARY AT WWW.CWN-RCE.CA

REPORT AUTHORED BY: LYNDA MCCARTHY, RYERSON UNIVERSITY AND JORGE LOYO, RICE UNIVERSITY

RESEARCH TEAM

LYNDA MCCARTHY, Ryerson University
CHRIS METCALFE, Trent University
WAYNE PARKER, University of Waterloo
PAUL SIBLEY, University of Guelph

PARTNERS

BLACK LAKE ENVIRONMENTAL
CITY OF CALGARY
CITY OF HALIFAX
CITY OF TORONTO
ENVIRONMENT CANADA
HALTON REGION
HYDROMANTIS ENVIRONMENTAL
LYSTEK INTERNATIONAL INC.
ONTARIO MINISTRY OF AGRICULTURE, FOOD AND RURAL AFFAIRS
ONTARIO MINISTRY OF THE ENVIRONMENT AND CLIMATE CHANGE
SYLVIS ENVIRONMENTAL

REFERENCES

A DETAILED LITERATURE REVIEW on issues related to ESOCs and pathogens in biosolids land application can be found at: http://www.cwn-rce.ca/assets/resources/pdf/McCarthy-Risks-Biosolids-2015.pdf

LISTEN TO A RECORDED WEBINAR discussing the results and implications of this research at: https://canadianwaternetwork.adobeconnect.com/_a1117068607/p1wtn3xcctk/.