Restoring Ecosystem Services in Degraded Urban Soils Using Biosolids and Soil Amendment Blends

Nick Basta
Professor of Soil and Environmental Chemistry
School of Environment and Natural Resources
The Ohio State University
Columbus, Ohio

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School of Environment and Natural Resources
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Environmental Science / Ecosystem Science
Terrestrial Wildlife and Ecology
Soil Science
Wetland Science / Ecosystems
Forest Ecosystems
Stream, Lake Ecosystems and Fisheries
Environmental Law, Policy and Social Science
Research program

- Soil/Environmental contaminant chemistry; ecotoxicology
  emphasis on environmental media (air, soil, dust, water, food)
  exposure and human and ecological risk assessment
- Development and evaluation of soil remediation technologies
- Beneficial use of organic residuals including biosolids

Personnel:
full time staff
Research Scientist; Research Assoc. /Laboratory Manager;
5 Research Assistants
3 graduate students and 5 part-time laboratory assistants
Revitalization of Degraded Urban Soils

Many urban soils and brownfields have lost their soil quality. These soils have lost their essential “ecosystem services, to support vegetation, support the food chain (earthworms for birds, etc), and recycle waste materials (dead vegetation, excess nutrients).

Degraded soils in Calumet, IL
High Quality Soil is the Foundation of a Healthy Ecosystem

Soil Quality: The capacity of a soil to function to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation.
High Demand for High Quality Soil

Topsoil Excavation from Farmland

“borrowed soil”

destruction of vital Natural Resource

Lower quality subsoil being used as value of farmland topsoil hits record highs

Solution: Manufactured Soil Blends

Compost, Animal Manure, Biosolids, and/or other bioproducts

Biosolids compost

MWRD Aged EQ Biosolids
Using Biosolids / Byproducts to Revitalize Degraded Land / Brownfields in Chicago

MWRDGC scientists are international leaders in restoration using their biosolids products

Unique Aged EQ Biosolids
Evaluating Biosolids Soil Blends and Compost for Soil Restoration and Revitalization in the Calumet Region

Ohio State University
- Dr. Nicholas Basta
- Dr. Richard Dick
- Dr. Roman Lanno
- Dawn Busalacchi
- Jennifer Tvergyak

Metropolitan Water Reclamation District
- Dr. Lakhwinder Hundal
- Dr. Kuldip Kumar
- Dr. Albert Cox
- Dr. Thomas Granato
Ohio State Research Team

Nicholas Basta
Professor of Soil/Environmental Chemistry, SENR
Dawn Busalacchi, Graduate Research Assistant (GRA)

Richard Dick
Professor of Soil Microbial Ecology
and Eminent Scholar, SENR
Jennifer Tvergyak, GRA

Roman Lanno
Professor of Water and Soil Ecotoxicology
Evolution, Ecology and Organismal Biology
Developed by many city, state, and federal agencies and area stakeholders

- Established SITE SPECIFIC Background, Threshold (NOAEL) & Benchmark (LOAEL) levels of contaminants in soil, sediment and surface waters of the region
- Our data was compared against THESE LEVELS
- recommended resurfacing with 2 inches of compost
Project Objectives

USFWS had concerns about the use of biosolids as a restoration material in the Calumet area. Vegetative compost (2 inches applied to surface) was proposed.

Therefore, this study compares biosolids / blends to vegetative compost performance in restoring ecological function to degraded sites, while minimizing environmental impact.
Research Field Location in Calumet, Illinois
Experimental Design - Randomized Runoff Plots

4 Treatments + control - 4 Replicates

- CS = Control soil
- VC = Vegetative compost 2.5 cm/1 in
- B1 = Biosolids 2.5 cm/1 in
- B2 = Biosolids 5.1 cm/2 in
- CT = Combination treatment of biosolids 2.5 cm/1 in + WTR + biochar
Water Treatment Residual (WTR) - added to bind excess soluble P

Biochar – added to absorb potential organic contaminants
Aaron Mali and Oulu Coquie rototill in the Soil Treatments
Plot installation and rainfall runoff collection

- Runoff collected for every rainfall event, for 3 yrs and analyzed for TSS, pH, EC, N, P and dissolved metals
- Microconstituents (PPCPs) analyzed by AXYS Analytical Labs
Plots were seeded with 33 native grass, legume and forb species from Cardno JFNew

- Soils sampled annually and analyzed for multiple constituents
- Laboratory earthworm bioassay conducted to measure mortality and reproductive endpoints

Results....
Select soil quality measures

Total Organic Carbon (TOC), measured as average of 4 replicates for each plot treatment, compared for each sampling year

Soil Treatments
CS VC B1 B2 CT
g kg⁻¹
0
20
40
60
80
100
120
YR 2009
YR 2010
YR 2011

Biosolids increased soil organic carbon, total N, plant available N (PAN) more than compost treatment
<table>
<thead>
<tr>
<th>Year</th>
<th>As</th>
<th>Ba</th>
<th>Be</th>
<th>Cd</th>
<th>Co</th>
<th>Cr</th>
<th>Cu</th>
<th>Mn</th>
<th>Mo</th>
<th>Ni</th>
<th>Pb</th>
<th>Sb</th>
<th>Se</th>
<th>V</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>13.4b†</td>
<td>12.8ab</td>
<td>12.3ab</td>
<td>12.2a</td>
<td>11.9a</td>
<td>1.20c</td>
<td>3.93a</td>
<td>7.61a</td>
<td>6.84b</td>
<td>41.4b</td>
<td>46.0b</td>
<td>3.93a</td>
<td>0.83a</td>
<td>49.3b</td>
<td>164a</td>
</tr>
<tr>
<td>2010</td>
<td>17.5b</td>
<td>13.2a</td>
<td>13.7a</td>
<td>13.1a</td>
<td>14.1a</td>
<td>1.11b</td>
<td>52.8a</td>
<td>46.8a</td>
<td>4.72ab</td>
<td>31.7a</td>
<td>34.8a</td>
<td>4.92a</td>
<td>31.4a</td>
<td>52.1a</td>
<td>200a</td>
</tr>
<tr>
<td>2011</td>
<td>11.4a</td>
<td>12.1a</td>
<td>12.7ab</td>
<td>13.5b</td>
<td>14.0b</td>
<td>1.14b</td>
<td>38.5a</td>
<td>41.6a</td>
<td>4.21a</td>
<td>38.3a</td>
<td>38.3a</td>
<td>4.21a</td>
<td>26.7c</td>
<td>35.2a</td>
<td>155a</td>
</tr>
<tr>
<td>2009</td>
<td>204a</td>
<td>183a</td>
<td>234ab</td>
<td>332b</td>
<td>221a</td>
<td>1.11b</td>
<td>1.14b</td>
<td>0.90a</td>
<td>0.37c</td>
<td>0.12a</td>
<td>0.23b</td>
<td>0.20b</td>
<td>0.28bc</td>
<td>204a</td>
<td>256b</td>
</tr>
<tr>
<td>2010</td>
<td>203b</td>
<td>136a</td>
<td>209bc</td>
<td>251c</td>
<td>227bc</td>
<td>1.11b</td>
<td>1.3bc</td>
<td>1.86d</td>
<td>NA‡</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>203b</td>
</tr>
<tr>
<td>2011</td>
<td>128a</td>
<td>130a</td>
<td>189c</td>
<td>210c</td>
<td>182b</td>
<td>0.12a</td>
<td>0.23b</td>
<td>0.20b</td>
<td>0.37c</td>
<td>0.12a</td>
<td>0.23b</td>
<td>0.20b</td>
<td>0.28bc</td>
<td>128a</td>
<td>124c</td>
</tr>
</tbody>
</table>

†Means within parameter measured with same letter are not different
‡ Not analyzed
§ Below detect limit

**Heavy Metal(loid)s in Soil**

BS treatments increased soil Cu and Zn; these levels are below any concern (including USEPA Ecological Soil Screening Levels). The addition of Cu and Zn and other micronutrients are beneficial because these are essential plant nutrients. Animals manure or biosolids provides micronutrients—compost doesn’t.
Phosphorus Saturation Index (PSI) = \( \frac{P_{\text{ox}}}{Al_{\text{ox}} + Fe_{\text{ox}}} \); values over 1 have been correlated with potential transport of labile (soluble) P

BS2 a concern; BS1 less concern
<table>
<thead>
<tr>
<th>Biological function</th>
<th>Soil Enzyme</th>
<th>Ecosystem service</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chitin degradation</td>
<td>N-Acetyl- β-glucosaminidase</td>
<td>C &amp; N Nutrient cycling; N fixation</td>
<td>-</td>
</tr>
<tr>
<td>Glucose availability</td>
<td>β-glucosidase</td>
<td>Microbial energy source; indirect heavy metal indicator</td>
<td>-</td>
</tr>
<tr>
<td>Inorganic N metabolism</td>
<td>Amidase &amp; urease</td>
<td>Supplies N to microbes</td>
<td>-</td>
</tr>
<tr>
<td>P availability</td>
<td>Acid &amp; alkaline phosphatase</td>
<td>P release for plant nutrition</td>
<td>-</td>
</tr>
<tr>
<td>Sulfate metabolism</td>
<td>Arlysulfatase</td>
<td>Indirect indicator of fungi; potential degradation of microconstituents</td>
<td>-</td>
</tr>
<tr>
<td>Broad based nutrient</td>
<td>Fluorescein diacetate (FDA)</td>
<td>Overall indicator of healthy soil biological activity</td>
<td>-</td>
</tr>
</tbody>
</table>
Select soil enzyme findings

- Biosolids and compost had a positive effect on soil enzymatic activities and microbial function.

- Biosolids treatments tended to have higher amounts of fungal biomass compared to control, as well as lower stress biomarkers.
Vegetative Performance and Quality

• Biosolids produced highest plant tissue N, thus improved protein content (nutrient) levels

• Biosolids DID NOT elevate trace metals in plants therefore no concern for ecosystem food chain transfer
Both biosolids and VC improved plant diversity

**Shannon-Weaver Values**

<table>
<thead>
<tr>
<th>Plot treatment</th>
<th>Grasses SW</th>
<th>Forbs SW</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>1.22</td>
<td>3.06</td>
</tr>
<tr>
<td>VC</td>
<td>4.41</td>
<td>1.83</td>
</tr>
<tr>
<td>B1</td>
<td>2.13</td>
<td>ab</td>
</tr>
<tr>
<td>B2</td>
<td>3.75</td>
<td>b</td>
</tr>
<tr>
<td>Bc</td>
<td>4.37</td>
<td>b</td>
</tr>
<tr>
<td>CT</td>
<td>5.24</td>
<td>c</td>
</tr>
</tbody>
</table>

Note: Values with different letters are significantly different.
Neither biosolids or compost increased earthworm mortality.
Both biosolids and compost treatments increased number of juveniles and earthworm reproductive success.
The 1st flush of runoff water (1st rainfall event) was tested for 14 dissolved metals:

- As, Ba, Be, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se & Zn

Findings:

- All metals below Calumet Ecotoxicology Protocols (LOAEL) except Cu for the 2-inch Biosolids.

No concern with BS1
Concentration of soluble total N in filtered runoff water sampled after 1st flush, and seasonally thereafter

Greater loss of soluble N associated with biosolids declined markedly to near background levels within 1 year
Concentration of soluble P in filtered runoff water sampled after 1\textsuperscript{st} flush, and seasonally thereafter

- Biosolids increased runoff P compared to compost
- Application of additional WTR in 2nd year was starting to have an impact on P levels
Microconstitutents
Pharmaceuticals and Personal Care Products

• 119 PPCP were tested by Axys Analytical Labs

• 20 compounds were measured above detection limits, concentrations ranged from approx 1 to 1760 ng L$^{-1}$ (Ibuprofen)

• 4 compounds detected in runoff from all treatments

• Concentrations were not above NOAEL (daphnia) and were below probable no-effect levels in literature (PNEC)
## Top 5 compounds, which were 10 times greater than detection limit

<table>
<thead>
<tr>
<th>Compound</th>
<th>Control</th>
<th>Compost</th>
<th>B2</th>
<th>CT</th>
<th>NOAEL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>ng L⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>nd</td>
<td>nd</td>
<td>66.0 - 206</td>
<td>nd</td>
<td>25,000</td>
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<tr>
<td>DEET</td>
<td>57.9 - 420</td>
<td>57.9 – 86.5</td>
<td>43.0 - 154</td>
<td>58.2 - 176</td>
<td>_</td>
</tr>
<tr>
<td>Gemfibrozil</td>
<td>3.41 – 15.0</td>
<td>7.05 – 84.0</td>
<td>35.8 - 119</td>
<td>90.3 - 324</td>
<td>100,000</td>
</tr>
<tr>
<td>Ibuprofen</td>
<td>nd - 202</td>
<td>89.7 - 568</td>
<td>527 - 1760</td>
<td>854 - 1490</td>
<td>5000</td>
</tr>
<tr>
<td>Valsartan</td>
<td>nd – 17.3</td>
<td>nd – 78.0</td>
<td>58.4 - 200</td>
<td>102 - 233</td>
<td>_</td>
</tr>
</tbody>
</table>
Conclusions

• Biosolids increased soil organic carbon and many soil quality measures more than compost

• Vegetative performance and community measures responded favorably to both compost and biosolids applications - biosolids response was more pronounced

• Microbial response to compost and biosolids applications were similar. Biosolids had greater nutrient cycling (enzymes) and fungal population than compost
Conclusions

- Soil invertebrates (earthworms) reproductive measures were increased by compost and biosolids.

- The biosolids applied at the 2 in rate exhibited potential for P runoff. However, 1 inch biosolids rate had much less concern. The WTR combined with biosolids showed some effect in reducing P runoff.

- PPCP levels in runoff were not detected or very low. They were below LOAELs and PNECs in the literature.
Recommendations

- Biosolids is recommended as a beneficial soil treatment at the 1 inch application rate.

- Use of best management practices to control erosion and runoff after establishment is essential. WTR should be used to reduce P in runoff.

- Vegetative compost balances the N:P ratio of biosolids, and biosolids contributes sustained release of plant nutrients, a combination treatment of both may be an optimal material, and merits further consideration.
Acknowledgements

Metropolitan Water Reclamation District of Greater Chicago or Funding this project and tirelessly helping with sample, data collection and research management
School of Environment and Natural Resources
Ohio State University

New Ecological Restoration Degree Program
B.S. Environmental Science /ER
M.S. and Ph.D. Environment Natural Resources ER
New faculty on board and hiring more
"There's nothing that cleanses your soul like getting the hell kicked out of you" -- Coach Woody Hayes
Thank you for your attention
More information?

Nick Basta
Soil and Water Environmental Laboratory
basta.4@osu.edu