Sustainable Sanitation to Improve Soil Remediation Potential of Human Manure-Based Soil Amendments

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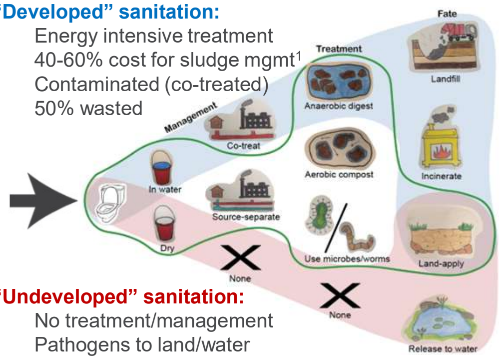
Goal 1: optimize sanitation

"Developed" sanitation:
- Energy intensive treatment
- 40-60% cost for sludge mgmt[1]
- Contaminated (co-treated)
- 50% wasted



Goal:
- Safe treatment
- Minimize resource requirements
- No contamination
- 100% to soil

"Undeveloped" sanitation:
- No treatment/management
- Pathogens to land/water

Fig. 1 Decision tree for humanure handling

Goal 2: integrate sanitation and remediation

Ex: Kabwe, Zambia (pop. 300k)[2]
- Broken Hill Pb/Zn Mine 1906-94
- Waste heap (needs removed)
- Pollution spread
- Affected by drought
- Unmanaged human waste compounds health risks

Fig. 2 Pb-rich dust in Kabwe, Zambia[2]

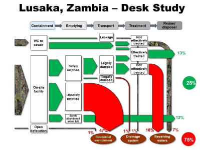


Fig. 3 Lusaka (capitol 80 mi from Kabwe): 75% of human waste unsafely managed[3]

Potential of organic amendments:
- Add OM and nutrients
- Buffer pH
- Increase water retention
- Stabilize metals
- Support vegetation
- Sequester carbon

Fig. 4 Terra Preta soil cultivated by indigenous tribes in the Amazon (biochar, excreta, compost)[4]

Sewered sanitation and conventional wastewater treatment is not always feasible and may not optimize end-product quality

Research questions

1. How does **management** and **treatment** of humanure affect the physico-chemical properties of the produced amendment?
   - *Properties: pH, organic matter, nutrients, salts, sorption capacity, state of carbon*
2. How do these properties affect the amendment's potential to support vegetation and reduce toxicity?
   - *Metrics: soil aggregate stability, water retention, reaction environment, leaching potential*

Hypothesis

Source-separated, aerobically composted human manure (humanure) will provide better soil remediation potential than conventional co-treated, anaerobically digested biosolids due to:
- Less contamination
- More aromatic and O-functionalized C

which will:
- Increase metal binding capacity
- Support soil formation
- Produce a more favorable environment for plant growth

Methods

Mine tailings (MT)

Pb-rich mine tailings collected from pile in Idaho Springs, CO

Fig. 5 Pile where tailings were collected

Amendments

Topsoil (TS)
- Sandy loam, low OM

Biosolids (BS)
- Anaerobic digestion
- Polymer added

Composted Biosolids (C-BS)
- 30% biosolids

Composted humanure (C-H)
- 1/3 human waste, 1/3 peat moss, 1/3 other waste
- 3-month aerobic, thermophilic compost (44 °C), turned ≥3x
- 6-month cure

Incubation (40 day)

Materials dried, ground, sieved <2 mm (except BS)
Vary wt% amendment
- 20, 40 wt% for TS
- 5, 10, 20 wt% for others

Maintain ~80% field capacity

Analysis (to date)

- Soils and amendments sent to CSU soil testing lab
- Mixtures air-dried
- pH/EC: 1:2 (w) slurry
- Water content: bottom-up saturation and 24 hr drain

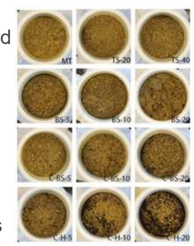


Fig. 6 Soil/amendment mixtures during incubation. "TS-20" indicates 20 wt% topsoil. All samples prepared in triplicates.

Findings (so far)

Soil/amendment properties

Table 1 mine tailing properties

Texture	Sandy Loam
pH	3.6
OM LOI (%)	1.9
Field capacity (%)	10.9
Pb (ppm)	~10k

Table 2 amendment chemical properties

	BS	C-BS	C-H
pH	7.4	7.98	4.2
Total C (%)	28.7	8	32.9
Total N (%)	5.34	0.93	3.2
P as P_2O_5 (%)	7.16	0.8	0.68
K as K_2O (%)	1.95	0.22	0.45
Soluble salts (mmhos/cm)	5.58	0.6	1.83
Ca (%)	13.17	1.18	1.78
Zn (ppm)	697	73	113
Fe (ppm)	18502	3788	6855
Cu (ppm)	323	20	20

Post-incubation properties

- TS did not affect water retention
- BS significantly increased water content, pH, and EC (high initial nutrient/salt/metal content)
- C-BS had little effect on water content, increased pH, and decreased EC
- C-H increased water content, barely increased pH (low initial pH), and increased EC at 20 wt%

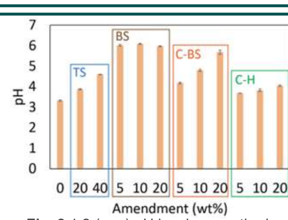


Fig. 8 1:2 (w:w) pH by slurry method

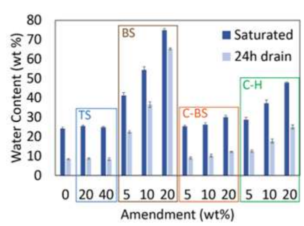


Fig. 7 Water content after bottom-up saturation and a 24-hr drain

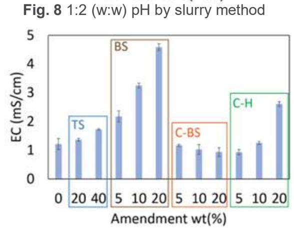


Fig. 9 1:2 electrical conductivity (EC)

Future measurements

Soil properties:
- Soil redox potential
- OM in soils – SOM LOI
- State of carbon – ^{13}C-NMR
- Soil formation – wet aggregate stability*

Toxicity metrics:
- State of Pb –XANES*
- Leaching potential – desorption study*

*to be measured with and without incubation

Feedback appreciated!! ☺

Past literature

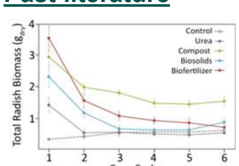
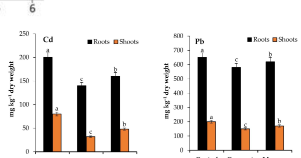


Fig. 7 Humanure-compost-amended soil yielded highest radish biomass over 6 crop cycles. Compost increased soil organic matter over 230-day period and reduced water leached, compared to biosolids. Adapted from Ryals, *et al.*[5]

Fig. 8 Lowest concentration of Cd/Pb in roots/shoots of wavy-leafed saltbush grown in soil with compost added. From Li, *et al.*[6]



Practical considerations

Sanitation infrastructure
- Sewers costly to build/maintain
- Solid waste collection: less fixed infrastructure, lower cost, implementation/transition costs

Amendment application
- Moisture content
- Transport costs
- Reapplication requirements

Table 3 amendment moisture contents

	BS	C-BS	C-H
Moisture (wt %)	79.3	4.3	6.1

Contaminant buildup over time (co-treated waste)
- Salt, metal, PFAS

Only part of solution: compost can stabilize low-level contamination after major pollution sources are removed or covered

Site-specific resources, capacities, and needs

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