Pulp and paper mill fiber sludges in agricultural water protection

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Luke in brief

VISION
A sustainable future and well-being from RENEWABLE NATURAL RESOURCES

MISSION
Through research, we create VALUE AND SOLUTIONS for our customers by solving local and global challenges

- Circular bioeconomy
- Profitable and responsible primary production
- Adaptive and resilient bioeconomy
- Competent personnel and motivating organisation
- Data-driven solutions
- Cross-sectoral and interdisciplinary collaboration
- Modern research platforms
- Climate smart carbon cycle

- We are one of the four Statistical Authorities in Finland.

125 M€
Turnover

73 M€
Budget funding

52 M€
External funding

25
Locations in Finland
HQ in Helsinki
Present in 12 campuses with universities, research institutes and polytechnics

1288
Employees
46 research professors
622 researchers

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Fiber sludge - from factory to farm

Pulp and paper mill fiber sludges in agricultural water protection

Soil structure, Nutrient leaching

Carbon

Pulp & Paper

Energy (bark)

Water treatment

Composting

Fiber sludge

Luke

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4-year data published

Financial support:
- Finnish Funding Agency for Technology and Innovation (Tekes/Business Finland) and the companies involved in the NSPPulp project: UPM-Kymmene Oyj, Metsä Fibre Oy, Stora Enso Oyj, Biolan Oy, Ekokem Oy, Outotec Finland Oy, Tyynelän maanparannus Oy
- Ravinnekuilu-project (2018-2019), financed by the Nutrient Recycling Pilot Programme (Finnish government key project)
- European Research Council (ERC) under the European Union’s Horizon 2020 research and innovation programme, grant agreement 818290 (CIRCLES).
Field experiment at Jokioinen

- Established at autumn 2015
  - Composted pulp mill sludge (CPMS)
  - Lime-stabilized pulp mill sludge (LPMS)
  - Fiber sludge (FS)
    - From pre-clarifier of cardboard machine process water
  - Unamended plots served as the control

5 replicates = 20 plots 6x15 m (120x15 m in total)
Soil amendments

- Fiber sludge nutrient poor
- CPMS&LPMS: phosphorus, nitrogen and cadmium content must be considered when applied
- Current practice ~40 t ha$^{-1}$

<table>
<thead>
<tr>
<th>Sludge</th>
<th>Moist t ha$^{-1}$</th>
<th>Carbon t ha$^{-1}$</th>
<th>P-tot kg ha$^{-1}$</th>
<th>N-sol kg ha$^{-1}$</th>
<th>N-tot kg ha$^{-1}$</th>
<th>Cd g ha$^{-1}$</th>
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<tbody>
<tr>
<td>CPMS</td>
<td>52</td>
<td>8</td>
<td>45</td>
<td>211</td>
<td>34</td>
<td>21</td>
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<tr>
<td>LPMS</td>
<td>51</td>
<td>9</td>
<td>53</td>
<td>30</td>
<td>32</td>
<td>16</td>
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<tr>
<td>FS</td>
<td>72</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>1</td>
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</table>
Rainfall simulation test

- Soil susceptibility to erosion and nutrient mobilization
- 30x40 cm soil monoliths taken to laboratory
- Simulated rain applied for 5 h d$^{-1}$ on two consecutive days at an intensity of 5 mm h$^{-1}$ (=25 mm d$^{-1}$)
- Percolation water samples were collected and analyzed
- Procedure repeated each spring 2016-2019 (+2020)

20 samples in each spring
Suspended solid (SS) and total phosphorus (TP)

- All products reduced SS and TP over 4-year period
- Reduction of SS in 1\textsuperscript{st} year >60\% and in 4\textsuperscript{th} year >30 \%
- Similar trend in TP
- Dissolved reactive P not affected by treatments
- Springs 2018 and 2019 were very dry, SS concentration in CTRL was halved
- Gradually subsiding effect of amendments or drying induced improvement of CTRL soil structure?
Dissolved organic carbon (DOC) and Total nitrogen (Tot-N)

- DOC concentrations stabilized after the first spring
  - 14-17 t organic matter ha⁻¹ was added
- Low Tot-N concentrations coincident with low yield of FS treatment in 1st year
  - Microbial immobilization
Electrical conductivity (EC) and pH

• Increase in percolation water pH in line with soil pH
• EC mostly below 300 µS cm\(^{-1}\)
  • In the case of gypsum, water EC >300 µS cm\(^{-1}\) promoted aggregate stability and flocculation of clay particles
• Mechanism behind stabilized soil structure?
  • interactions of soil minerals with the added organic matter and microbe-derived compounds
Soil carbon (C%) and cadmium (Cd) content, electrical conductivity (EC) and pH

- No clear increase in soil carbon content after 4 years
  - New sampling 2020, advanced study methods used!
  - Results leans towards fast microbiological decomposition
- Liming effect, pH increased 0.2-0.6 pH Unit
- Slight increase in soil electrical conductivity
- No effect on soil Cd content

<table>
<thead>
<tr>
<th>Treatm.</th>
<th>C %</th>
<th>p</th>
<th>EC mS cm⁻¹</th>
<th>p</th>
<th>pH</th>
<th>p</th>
<th>Cd mg kg⁻¹</th>
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<tbody>
<tr>
<td>FS</td>
<td>2.34</td>
<td>0.767</td>
<td>0.87</td>
<td>&lt;.0001</td>
<td>6.81</td>
<td>&lt;.0001</td>
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<td>0.71</td>
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<td>6.25</td>
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Yields

Fertilization

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<th>2016</th>
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<th>2018</th>
<th>2019</th>
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<tr>
<td></td>
<td>N</td>
<td>N</td>
<td>P</td>
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<tr>
<td>CPMS</td>
<td>90</td>
<td>80</td>
<td>-</td>
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<tr>
<td>Ctrl</td>
<td>120</td>
<td>85</td>
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<td>90</td>
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</tbody>
</table>

Grain yield, kg ha\(^{-1}\)

- 2016
- 2017
- 2018
- 2019

~500 kg

14% difference

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Soil microbes 3 year after amendment

- The amendments increased basal respiration in spring and microbial biomass in autumn
- The amendments clearly changed the fungal and bacterial community composition
- *Sebacinales* ~300-700% increase
  - Indicator for less intensive land use typical in organic farming
- *Funneliformis mossae* ~200% increase
  - Arbuscular mycorrhiza fungi, nutrient uptake
- *Tetracladium marchalianum* ~230% increase
  - Fungi, efficient aggregator
- **Positive association** but no direct evidence that microbiological activity explains improved soil stability!
Ongoing projects

- KUITU-Project studies CPMS as water protection measure in catchment-scale
  - https://www.luke.fi/kuitu/
  - On-line water quality measurement installed 2019, fiber application at autumn 2021
- Biosfäär-project, fibers in coarse textured soil (2020→)
- Viivi-project, fiber sludge in vegetable production (2021→)
- Maa- ja vesitekniikan tuki ry (2021→)
  - Helium ion microscopy and X-ray microtomography
  - Organo-mineral associations, aggregate 3D structure
- EU-H2020-project CIRCLES
  - Soil microbial communities and activities using new metagenome and metatranscriptome analyses
Thank you!