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The potential use of sewage sludge biochar in green roof substrates for P recovery and carbon sequestration

Ferdinand Hartmann[1], Katharina Mauss[2], Gerhard Soja[1], David Gansterer-Heider[1], Christoph Pfeifer[1]

Phosphorus: A Critical Raw Material

Phosphorus (P) is an essential nutrient for plant growth, and its use plays a central role in global food security. At the same time, **geological phosphorus reserves are limited** and concentrated in a small number of geopolitical regions. Alongside approaches for more efficient nutrient use in agriculture, the **recycling of phosphorus** from secondary sources is gaining increasing importance.

Phosphorus Recycling from Sewage Sludge

Sewage sludge contains large amounts of phosphorus, but its direct agricultural use is challenging due to potential contaminants and hygienic risks. Pyrolysis offers an innovative solution here:

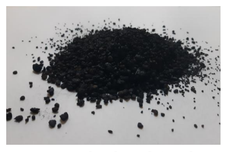
- Elimination of pathogens
- Conversion of organic carbon into stable carbon compounds (CO_2 storage)
- Elimination of organic pollutants (e.g., PAHs, PFAS)

This results in a mineral-stable, nutrient-rich material that opens up new application possibilities in the spirit of the circular economy.

Sewage Sludge Pyrolysis

The **sewage sludge biochar** was produced using a Pyreka screw reactor from Pyreg GmbH) at the Institute of Chemical and Energy Engineering, (BOKU University).

Sewage sludge from the treatment plants in Vienna and Baden was used and pyrolyzed in a screw reactor at 400°C and 700°C with a residence time of **20 minutes**.



sewage sludge biochar

Pyreka – screw pyrolysis:



Model Green Roofs

A commercial green roof substrate (Claylith, certified to ÖNORM B 1131) was blended in at 10% (v/v), and Italian ryegrass (*Lolium multiflorum, cultivar "Gemini") was sown.*



Treatments:

- Control (Claylith only)
- SSB_V400 (Vienna; at 400°C)
- SSB_V700 (Vienna; at 700°C)
- SSB_B400 (Baden; at 400°C)
- SSB_B700 (Baden; at 700°C)
- BC (biochar from plant material)

Use of Sewage Sludge Biochar in Green Roof Substrates

Green roofs make an important contribution to climate-resilient cities:

Ecological benefits

- Stormwater retention → reduction of surface runoff and flooding risk
- Cooling → mitigation of urban heat island effects
- Biodiversity → habitats for plants, insects and birds
- Air quality → dust binding and CO_2 reduction

Economic benefits

- Improved building efficiency through enhanced thermal insulation
- Extended service life of roof waterproofing (protection from UV, temperature and weathering)

Potential of biochar/sewage sludge char in green roof substrates:

Substrate function & water management

- Increased water holding capacity due to porous structure
- Delayed release of precipitation water
- Potential to improve plant availability of nutrients

Climate protection & carbon storage

- Long-term carbon storage within the system (carbon sink potential)
- Contribution to municipal climate strategies & net-zero targets
- Integration into climate adaptation & circular economy strategies

Resource conservation & circular economy

- Substitution of primary raw materials (e.g., peat, mineral aggregates)
- Material recycling instead of final thermal treatment

Why use sewage sludge char in green roofs?

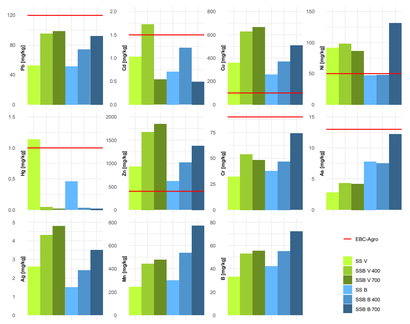
- Application in confined substrate systems on roofs rather than in agricultural soils
- Controlled installation setting with minimal exchange with natural soils
- Recycling of phosphorus and long-term sequestration of carbon

In this way, sewage sludge biochar can be put to meaningful use while closing material cycles and making cities more climate-resilient at the same time.



Results

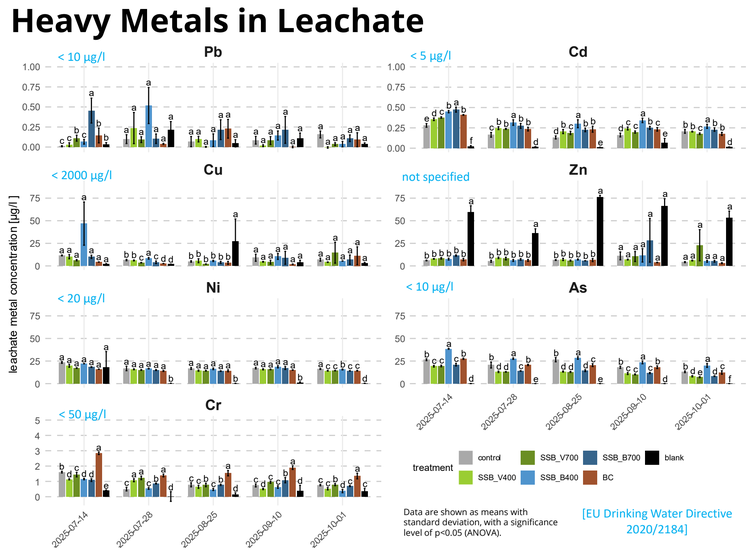
Sewage Sludge Biochar



Parameter	Limit value EBC-Agro	SS V	SS B	SSB V400	SSB V700	SSB B400	SSB B700
Naphthalene		0.6	0.8	0.7	2.0	0.9	2.9
Acenaphthylene		< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1
Acenaphthene		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Fluorene		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Phenanthrene		0.4	0.4	0.2	1.1	0.3	1.7
Anthracene		< 0.1	< 0.1	< 0.1	0.3	< 0.1	0.4
Fluoranthene		0.3	0.4	< 0.1	1.2	0.2	0.4
Pyrene		0.3	0.3	< 0.1	1.5	0.2	0.5
Benz(a)anthracene		0.1	0.2	< 0.1	0.2	0.1	0.3
Chrysene		0.1	0.1	0.1	0.8	0.2	0.9
Benzo(b)fluoranthene		0.2	0.2	< 0.1	< 0.1	0.2	< 0.1
Benzo(k)fluoranthene		< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Benzo(a)pyrene		< 0.1	0.1	< 0.1	< 0.1	0.1	< 0.1
Indeno(1,2,3-cd)pyrene		0.2	0.1	< 0.1	< 0.1	< 0.1	< 0.1
Dibenz(a,h)anthracene		0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Benzo(g,h,i)perylene		0.2	0.1	< 0.1	< 0.1	0.1	< 0.1
Total 8 EFSA-PAH excl. LOQ	< 1.0	0.9	0.8	0.7	1.0	0.7	1.2
Total 16 EPA-PAH excl. LOQ	< 6.0	2.5	2.7	< 0.1	7.2	2.3	7.1
Benzo(e)pyrene	< 1.0	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1
Benzo-(j)-fluoranthene	< 1.0	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1

- Limit values for the sewage sludge biochar are exceeded for **Cu**, **Ni**, **Zn**, (Cd).
- The **PFAS** measured in the sewage sludge chars were below the limit of quantification at both pyrolysis temperatures.
- Low **PAH** concentrations at 400°C (below the EBC threshold); however, at 700°C renewed formation occurred (naphthalene, phenanthrene, fluoranthene, pyrene, chrysene, etc.).

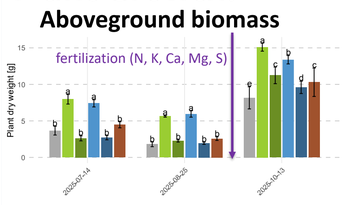
Heavy Metals in Leachate



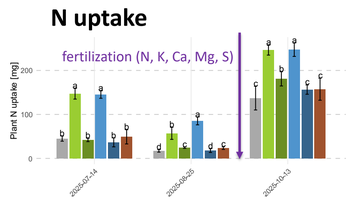
- With the exception of **As** and **Ni**, the heavy metal concentrations are clearly below the drinking water limit values for all treatments
- The base substrate is often contributing substantially to the total heavy metal contents in the leachate i.e., the heavy metal content is only partly originating from the sewage sludge biochar
- **Zn** was elevated in the blank samples:
→ Atmospheric deposition
→ Filtering effect of the substrates

Plant Growth:

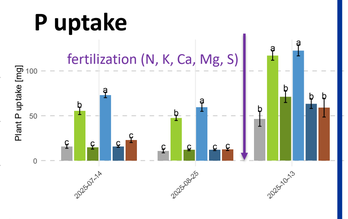
Aboveground biomass



N uptake

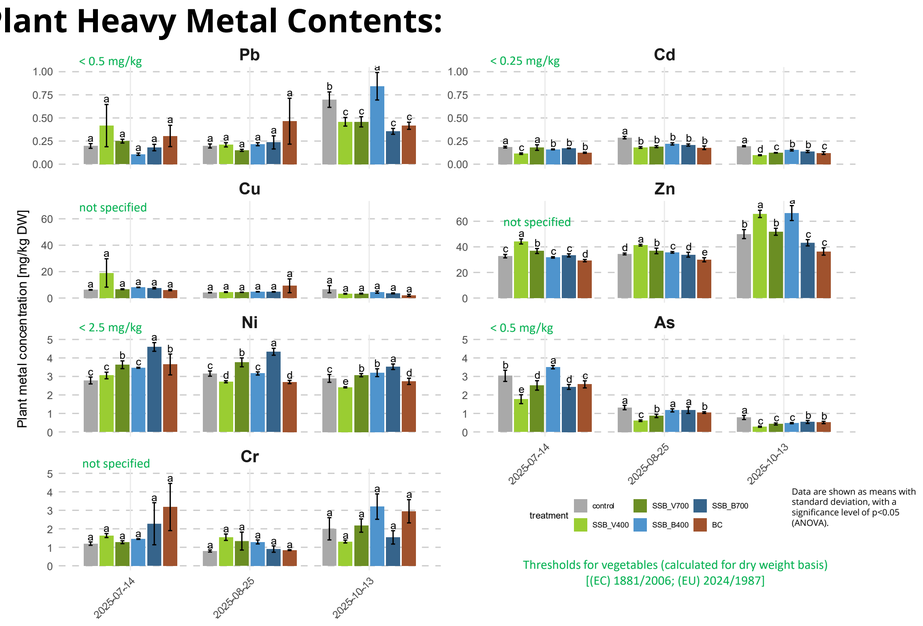


P uptake



- Higher plant biomass and N and P uptake for the 400°C variants.
- Fertilization (without P) in late summer after the second cut increased plant growth in all treatment groups. Nevertheless, the 400°C treatments showed the best overall growth.

Plant Heavy Metal Contents:



- Comparisons with limit values for vegetables provide a point of reference for the heavy metal levels (even though cultivation for food purposes is not intended).
- In some cases, values were above the limit values, though only slightly compared to the control.

Conclusion

- Our findings provide positive results regarding the **suitability of sewage sludge char for green roof substrates.**
- **Lower pyrolysis temperatures** are advantageous for **nutrient availability** and for avoiding PAH re-formation and were sufficient to remove PFAS from the biochar.

Institution 1: Universität für Bodenkultur Wien
Contact Person: Ferdinand Hartmann
E-Mail: ferdinand.hartmann@boku.ac.at

BOKU UNIVERSITY

Institution 2: GRÜNSTATTGRAU
Contact Person: Katharina Mauss
E-Mail: katharina.mauss@gruenstattgrau.at

GRÜN STATT GRAU

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