



University of Pannonia
Doctoral School of Chemistry and Environmental Sciences

**Utilization of red mud as a secondary raw material with
industrial/municipal waste**

DOCTORAL (PH.D) THESIS

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Introduction

Aluminum is the third most abundant element in the lithosphere after oxygen and silicon. Its use is widespread in the packaging industry, transportation, and various areas of the construction industry. The byproduct of alumina production from bauxite is highly alkaline (pH 12) red mud (RM). Approximately 1.5 tons of RM is generated for every ton of alumina produced from bauxite. To produce one ton of aluminum with 99.5-99.9% purity, about 1.9 tons of bauxite residue (red mud) is required. Despite efforts to utilize bauxite residues, the quantity of stored RM in reservoirs continues to increase. According to global waste records, the amount of RM reached 2.7 billion tons in 2007, exceeding 3.5 billion tons in 2014, with an annual increase of 100-120 million tons. Given this enormous amount of waste, the question arises whether this vast quantity of red mud could be reused for some purpose.

One of the most important and increasingly emphasized tasks today is to maximize the utilization of industrial and household waste and reduce their disposal. In the spirit of the circular economy, techniques and technologies that promote recycling are preferred, and complete, waste-free utilization would be the most beneficial. However, despite long-standing research and promising results, there has not yet been an economically applicable process to efficiently utilize large quantities of red mud with minimal waste.

The aim of this doctoral thesis is to investigate the use of red mud (RM) enriched with phosphorus (P) from wastewater and other waste materials as a soil substitute in reclaimed areas for the cultivation of energy crops or greening purposes. The created soil substitutes were examined through microcosm experiments, monitoring the growth intensity and morphological features of plants, as well as the changes in the root zone microbiome.

Based on my results, it can be concluded that the RM utilization technology presented in the thesis meets all the criteria set against the utilization of red mud: it can be used in large quantities, economically, with minimal waste formation, aligning with the expectations of the circular economy.

Applied Methods

During my research, taking advantage of the thixotropic rheological properties of RM, I developed a new "wet" mixing procedure. This allows the RM to be used not only in laboratory experiments but also in field experiments on a large scale. I examined three types of soil substitutes containing red mud (15-30% w/w) in microcosm experiments. To validate my laboratory results, I also tested a mixture containing sewage sludge and red mud in size-enlarged experiments with energy plants. During the root zone analysis, up to 30% RM did not prove toxic to the naturally occurring microbiome of the soil substitute containing compost. I identified specific bacteria that contributed to the development of *Sinapis alba* test plants even in a soil mixture with 30% RM. Bacteria such as halotolerant *R. cellulolyticum* and *P. peli*, which proliferated in response to RM, played a potentially significant role in promoting plant growth through

assumed phosphorus (P) mobilization, nitrogen (N₂) fixation, indole acetic acid (IAA), exopolysaccharide production (EPS), and aminocyclopropane-1-carboxylate (ACC) deaminase production.

In the medium containing sewage sludge, the above-ground part of the plants developed less, while the underground part developed better compared to the control soil. The P content of the soil matrices containing sewage sludge increased, while the Ca content decreased compared to the other substrates. The concentrations of Pb, Ni, Ti, and Si increased in parallel with higher RM content in the mixtures, but only Ni exceeded the limit set by Hungarian regulations (6/2009. (IV. 14.) KvVM-EüM-FVM). Si and Ti had a favorable effect on plant growth, compensating for the potentially toxic effects of Pb and Ni.

In the size-enlarged field experiments, good germination and growth were observed with 15% and 30% RM dosage, using different tree and energy plant species.

In my thesis, I examined the phosphorus binding capacity of RM. I investigated the possibilities of recovering phosphorus from synthetic P solution, wastewater from a poultry processing plant, enriched wastewater from a municipal wastewater treatment plant, and leachate from a landfill. My results show that the removal efficiency was 0.41-1.24 mg P/mg RM for discharged wastewaters and 0.10-0.13 mg P/g RM for leachate, despite the doses being significantly higher than the stoichiometric value (103 mg P/g RM). Despite a 50% increase in costs, the increased dosage did not result in significant cost escalation in terms of economic utilization.

Theses

- I. I have developed a new wet mixing process, exploiting the thixotropic properties of red mud, to produce a homogeneous mixture of red mud and other waste. The procedure can be used not only in culture tank experiments but also in field experiments to produce large quantities of soil replacement media.

Related publications. SOMOGYI, (2021): *Red mud with other waste materials as artificial soil substitute and its effect on Sinapis alba*. Journal of Environmental Management 287/112311. ISSN: 0301-4797. 2021.

- II. I have demonstrated that the combined effect of red mud and other waste materials as soil substitute medium has a positive effect on the herbaceous test plant *Sinapis alba*.
 - a) Based on the results of a series of experiments, I found that soil replacement media containing 15 and 30 m/m% red mud are suitable for growing the plants in reclaimed areas under controlled conditions. Germination, germination and morphological changes in the adult test plant were not caused by 30 m/m% red mud. In the case of degraded soils with highly eroded properties, a red mud content of 15 m/m% already improved the physical and water balance parameters of the test medium.

Related publications K. M. BERTA, R. KURDI, P. LUKÁCS, M. PENK, V. SOMOGYI, (2021): *Red mud with other waste materials as artificial soil substitute and its effect on Sinapis alba*. Journal of Environmental Management 287/112311. ISSN: 0301-4797. 2021.

- b) Elemental analysis showed that the test plant selected for the experiments, *S.alba*, was not susceptible to excessive accumulation of any of the elements tested, except titanium. It was concluded that the soil replacement medium containing the tested red mud and waste sludge could be used for the cultivation of plants (even energy crops) that are not prone to bioaccumulation, in reclaimed areas under controlled conditions.

Related publications K. M. BERTA, R. KURDI, P. LUKÁCS, M. PENK, V. SOMOGYI, (2021): *Red mud with other waste materials as artificial soil substitute and its effect on Sinapis alba*. Journal of Environmental Management 287/112311. ISSN: 0301-4797. 2021.

III. I proved that the combined effect of a soil replacement medium containing red mud and sewage sludge has a positive effect on woody test plants in a scale-up experiment.

- a) The experimental results show that a soil replacement medium containing red mud and sewage sludge is highly effective in size-limited experiments with woody test plants. It has resulted in good establishment and growth in trials of Sil, White Cottonwood, White Acacia and Sida energy plant. The soil replacement medium created is excellent for reclamation in degraded, highly eroded areas under controlled conditions.

Related publications: B. HEIL, D. HEILIG, V. CSANÁDY, K.M. BERTA, R. KURDI, R. FEJES, G. KOVÁCS (2022): *Effects of Red Mud on Plant Growth in an Artificial Soil Mixture*. Acta Silvatica et Lignaria Hungarica 18 (2), 151-166

IV. I have shown that red sludge causes an increase in acid-forming bacteria, which accelerates the decomposition of organic matter. I have shown that the acidifying bacteria in the root zone, which were increased by the red mud, contributed to the uptake of phosphorus, which is necessary for the development of plants.

- a) This is the first study showing the putative positive effect of *R. cellulolyticum* and *P. peli* on the growth of *S. alba* in a 30% red mud soil mixture.
- b) Even at 30%, red mud had no toxic effect on the bacteria in the soil replacement medium during the 30-day incubation.

Planned publication (forthcoming): K. M. BERTA, R. KURDI, P. KESSERŰ (2024): *Rhizobiome analysis of Sinapis alba in red mud with green waste compost materials as artificial soil substitute*.

- V. I have demonstrated that red mud powder is effective in removing phosphorus from waste water. Phosphorus-rich red mud can be used as a soil substitute medium for red mud in areas awaiting reclamation, thus reducing the use of high nitrogen fertilizers.
- a) The red mud removes phosphorus from waste water in 30 close doses (from 10 mg/l P content to 0.2 mg/l P content) with 20 minutes of mixing compared to commercially available liquid coagulants.
 - b) The cost of the process would increase by 50%, but the resulting material could be used as "raw material" in the plant experiments described earlier, instead of disposing of the waste from the experiments in landfills.

Related publications. V. SOMOGYI, V. PITÁS, K. M. BERTA, R. KURDI, (2022): *Red Mud as Adsorbent to Recover Phosphorous from Wastewater Streams*. Sustainability 14 (20), 13202. ISSN: 0301-4797. <https://doi.org/10.3390/su142013202>

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2. K. M. BERTA, R. KURDI, P. KESSERŰ (2024): Rhizobiome analysis of Sinapis alba in red mud with green waste compost materials as artificial soil substitute. Science of The Total Environment (folyamatban lévő)
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