From Biomass to Fertilizer: The Role of Chemical Processes in Addressing Agricultural Challenges of the 21st Century

Katarzyna Chojnacka[1]

[1]Department of Advanced Material Technologies, Wrocław University of Science and Technology, 50-370 Wrocław, Poland

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Presenting author email: katarzyna.chojnacka@pwr.edu.pl

Agriculture faces the dual challenge of sustaining productivity while reducing environmental impacts. Biomass valorization offers a viable pathway, transforming organic residues into value-added fertilizers. An estimated 3.7×10^9 tonnes of agricultural and 1.3×10^9 tonnes of food waste are generated annually (Chojnacka et al., 2020), containing essential nutrients (N, P, K, micronutrients) recoverable for soil application. The 2022 fertilizer crisis, marked by ~150% price increases, underscored the need for alternative, local nutrient sources (Savage et al., 2022).
This study presents a comprehensive innovation chain: raw material analysis, chemical conversion, biosorption, granulation, pilot validation, field testing, and CE certification under Regulation (EU) 2019/1009. Candidate feedstocks (e.g., crop residues, digestate, algae) are assessed for nutrients and safety via ICP-OES, AAS, and HPLC. Pre-treatments such as ash acidification or protein hydrolysis enhance nutrient bioavailability (Chojnacka et al., 2020). For example, digestate and ash were combined into a balanced fertilizer (Grigatti et al., 2019).
Biosorption is employed to enrich biomass with Zn, Cu, Mn, and Fe. Biomass types (e.g., peat, bark, seaweed) are exposed to micronutrient solutions under controlled pH and temperature. Metal ions bind to functional groups in cell walls, forming organically chelated fertilizers with slow-release properties and reduced leaching (Tuhy et al., 2014). The biosorbent matrix is biodegradable and non-phytotoxic.
Zinc-enriched biosorbents were compared with $ZnSO_4$ and Zn-EDTA in cress (Lepidium sativum) trials. No phytotoxic effects were observed, and biomass production increased (Table 1). These findings support biosorption as a viable fertilization strategy (Samoraj et al., 2016).

Table 1. Germination and biomass response of cress to zinc fertilizers (adapted from Tuhy et al., 2014; Samoraj et al., 2016)

Treatment	Germination (%)	Biomass (% of control)
Control (no Zn)	95 ± 2	100
$ZnSO_4$ (inorganic)	90 ± 3	110 ± 5
Zn-EDTA (chelate)	92 ± 1	108 ± 4
Bio-based Zn fertilizer	96 ± 2	115 ± 6
Bio-based Zn + seaweed ext.	98 ± 1	120 ± 5

a Values are means (n = 3). Seaweed extract added at 0.2% w/w.

Granulation transforms the enriched biomass into 2–5 mm granules using lignosulfonate binders. Granules showed high uniformity and mechanical strength. A 200 L pilot run yielded ~15 kg/batch with >90% Zn uptake (Samoraj et al., 2016). Leaching tests confirmed slow-release behavior.
Field trials demonstrated increased nutrient uptake and yield. In wheat, Zn biofortification was 25% higher than with conventional $ZnSO_4$. Treated soils showed enhanced microbial activity. Additives such as seaweed extracts and biochar improved plant vigor, water retention, and microbial synergy (Khan et al., 2009; Guo et al., 2023). Natural chelators (e.g., amino acids) further supported micronutrient availability (Intermag, 2023).
The final product met EU fertilizer standards: nutrient content was within specification, organic matter >30%, and heavy metals below thresholds (European Parliament & Council, 2019). CE certification was obtained in 2024.
The outlined chemical approach enables biomass-to-fertilizer transformation via sustainable, scalable processes. The resulting fertilizers support circular economy objectives, reduce import dependence, and contribute to climate-resilient agriculture.

References

Chojnacka, K., Moustakas, K., & Witek-Krowiak, A. (2020). Bio-based fertilizers: A practical approach towards circular economy. *Bioresource Technology, 295*, 122223.
European Parliament & Council. (2019). Regulation (EU) 2019/1009 on EU fertilising products. *Official Journal of the European Union, L170*, 1–114.
Grigatti, M., Giorgioni, M. E., Chiarini, L., & Ciavatta, C. (2019). Use of digestate and biomass ash for fertilizer formulation. *Waste Management, 85*, 245–252.

Guo, F., Wei, X., Wang, L., & Cheng, K. (2023). Biochar-based fertilizers and their impact on soil microbiota. *Science of the Total Environment, 865*, 161095.
Intermag. (2023). Innovative micronutrient fertilizers. Retrieved from https://www.intermag.pl
Khan, W., Rayirath, U. P., Subramanian, S., et al. (2009). Seaweed extracts as biostimulants. *Journal of Plant Growth Regulation, 28*(4), 386–399.
Samoraj, M., Tuhy, Ł., Rusek, P., Rój, E., & Chojnacka, K. (2016). Pilot-scale biosorption for micronutrient fertilizers. *BioResources, 11*(1), 400–413.
Savage, S., Brzeziński, B., De Lorenzo, D., & Wax, E. (2022). Agriculture winners and losers of 2022. *Politico*. Retrieved from https://www.politico.eu/article/agriculture-and-food-eu-sanctions-fertilizers-ukraine-russia-food-crisis-winners-and-losers-of-2022
Tuhy, Ł., Samoraj, M., Michalak, I., & Chojnacka, K. (2014). Biosorption for micronutrient fertilizer production. *Applied Biochemistry and Biotechnology, 174*(4), 1376–1392.