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Functional Recycling of Biobased, Borate-Stabilized Insulation Materials As B Fertilizer

Olivier Duboc,[†] Konrad Steiner,[‡] Frank Radosits,[†] Walter W. Wenzel,[†] Walter Goessler,[§] and Jakob Santner*[,∥]

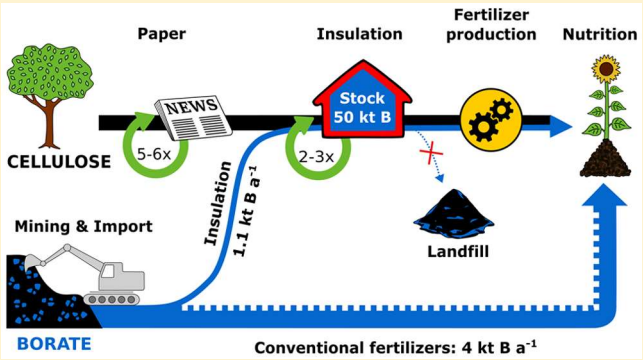
[†]Institute of Soil Research, University of Natural Resources and Life Sciences, Konrad-Lorenz-Strasse 24, 3430 Tulln, Austria

[‡]Höhere Bundeslehranstalt für Landwirtschaft Ursprung, Ursprungstraße 4, 5161 Elixhausen, Austria

[§]Institute of Chemistry, Karl-Franzens-Universität Graz, Universitätsplatz 1/I, 8010 Graz, Austria

[∥]Institute of Agronomy, University of Natural Resources and Life Sciences, Konrad-Lorenz-Strasse 24, 3430 Tulln, Austria

ABSTRACT: Boron is a finite resource, which has been listed as a critical raw material in the EU since 2014. Glass, frits and ceramics production, as well as fertilizers are among the major uses of B. Moreover, about 50 000 t B have been applied as fire retardant and pest repellent in cellulose fiber insulation (CFI) in Europe since the 1980s. Here we propose the end-of-life utilization of borated CFI as B fertilizer, to decrease societal B consumption and to avoid costly and potentially environmentally harmful CFI incineration and deposition in landfills. In a case study, we show that CFI biochar can provide substantial amounts of B to rapeseed and sunflower, with the B plant-availability being comparable to sodium tetraborate, a conventional B fertilizer. The annual B fertilizer consumption of the EU is estimated at ∼4000 t B yr^{-1}, which could be sustained by the B currently installed as CFI for >10 years. In addition, the annual use of B in CFI of 1100 t B yr^{-1} could cover ∼25% of the annual B fertilizer demand of the EU. Hence, conversion of CFI to B fertilizer provides a meaningful end-of-life strategy, which would contribute to a more resource-efficient and sustainable economy and to several of the UN Sustainable Development Goals.



INTRODUCTION

Boron, an essential plant micronutrient, is listed as critical raw material (CRM) in the EU since 2014.[1] As the global B reserves—mostly Na- and Ca-borates—are concentrated in a few countries, the EU is completely dependent on imports.[2,3] Only one country, Turkey, accounts for 38% of the global borate production and for 98% of the EU's borate supply.[3] The main uses for borates in the EU are glass (60%), frits and ceramics (10%), fertilizer (12%), and other products (18%) such as construction materials, catalysts, coatings, and detergents.[2]

Globally, borate reserves and annual production are estimated to 3.4×10^8 and 3×10^6 t B, respectively.[4] Thus, the exploitable reserves will only last for 110 years at the current rate of production. Notably, these figures are only a rough estimate because reserves are regularly updated, and annual ore extraction rates fluctuate depending on the market demand. Nevertheless, several authors have already pointed to an upcoming scarcity of B.[5,6]

Boron is essential for plant cell wall structure and is suspected to have further functions in cell membranes yet to be demonstrated.[7] Soil B deficiency, as identified by crop response to B application and soil analysis, can be observed globally, especially in large areas of northern Europe and the eastern regions of North America and China.[8] Soils exhibiting coarse texture, low organic matter content, high pH, and humid environment are particularly prone to B deficiency.[8,9] The annual consumption of B fertilizer in the EU is estimated between 3000 and 5000 t B, with 3−4 million ha fertilized with ∼1 kg B ha^{-1} yr^{-1}.[2,8] Boron fertilization is essentially based on crushed ores or their refined products, while B-rich waste products were used as fertilizer in a few cases only.[8]

Reuse of secondary raw materials as fertilizer has become an important aspect of the Circular Economy Action Plan adopted by the EU Commission in 2015.[10−12] Currently, the functional recycling rate of B in the EU, i.e., the reuse of a B-rich material for replacing the function of a primary B-containing resource, is estimated to only 0.6%,[13] which is mainly the reuse of biogenic wastes (food waste, manures, and sludges) as soil amendment or fertilizer.[2] It is therefore crucial to increase the rate of functional recycling of B, to reduce dependency on imports and unnecessary wastage of a

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