

Recovering Phosphorus from sewage sludge via biochar

Pyrolysis of sewage sludge can be a key enabling technology for more circular and sustainable P management while also addressing several pressing waste management challenges. By converting biosolids into stable, carbon-rich biochar, pyrolysis concentrates P into solid forms that can be recovered, transported, and formulated as fertilizers, helping to offset declining phosphate rock reserves. At the same time, high temperatures destroy pathogens and many organic contaminants, and can immobilize heavy metals in less mobile mineral phases, lowering risks associated with land application of untreated sludge.

Phosphorus (P) is an essential plant fertilizer and thus key to sustaining global food production. Over the last 100 years, the world has relied heavily on fossil-derived P sources, but high-quality phosphate rock reserves are in sharp decline, creating a growing need for alternative, more sustainable approaches to P fertilization. Waste streams often contain high levels of nutrients, and new efforts are underway to recover P from various kinds of phosphorus-rich waste. Sewage sludge (SS) and **biosolids are rich sources of P** that could potentially help reduce dependence on conventional mineral P inputs.^{1–3}

Switzerland was the first country to make P recovery from sewage sludge mandatory, with the introduction in 2016 of the revised Ordinance on the Avoidance and Disposal of Waste. It requires the recovery and recycling of P from wastewater, sewage sludge, sewage sludge ash, and animal/bone meal, with a transition period up to 2026. The amended Environmental Protection Act requires that P be recovered and returned to the economic cycle as marketable products (e.g., fertilizers or phosphoric acid), with at least 16 kg/P recovered per tonne of sewage sludge dry matter.

Land application of biosolids was a widespread practice globally, recently thwarted by an overwhelming body of evidence that it can contaminate soils, water bodies, food crops, etc with various hazardous substances (PFAS, pharmaceuticals, heavy metals, and more) concentrated in SS. Several countries have since started to strictly regulate the practice. Meanwhile, pyrolysis has emerged as an attractive alternative, one that produces a carbon- and nutrient-rich substance with many applications in soil amendment and beyond. SS biochar (SSB) is not only an excellent soil amendment, but also a multifunctional material for carbon sequestration, contaminant immobilization, and greenhouse gas emissions reduction.⁴

P Fertilization for plants: a primer

Plants are not able to utilize just any form of P. How much P is available to them depends on how easily P can move from different soil pools into the soil water around the roots of crop plants. In simple terms, P is “bioavailable” when it is in the right chemical form for plants or soil microorganisms to take it up. The most important of these forms is the orthophosphate ion,

which plants can use quickly over the short term. Some P in soil is tied up in minerals or organic matter and cannot be used right away; organic P must first be broken down by microbes to release orthophosphate. Less soluble P compounds matter because they can slowly dissolve or “buffer” the soil solution, helping keep enough P available over time.

P is the nutrient found in the highest concentrations in SSB, but it is present in various organic and inorganic fractions with different degrees of stability and bioavailability to plants. The concentration of each form of P in SSB depends on pyrolysis conditions such as temperature, heating rate and residence time.⁵

Crop and soil scientists have been investigating the effect of SSB as a soil amendment and their results suggest that it has potential as a source of P fertilization. SSB was shown to increase the yield of several crops, including those with short (e.g., radishes)⁶ and long (e.g., corn)⁷ lifecycles. Other studies indicate that SSB can serve as a P reservoir for soils, and that a fraction of this P is in available forms for plants.⁸ However, it is important to note that the bioavailability of P from SSB varies significantly with the biochar type and pyrolysis conditions, mainly temperature. Some studies suggest that total P increases with pyrolysis temperature, but its bioavailability declines at higher temperatures.² This is an active area of scientific investigation.

P content in sewage sludge biochar from Bioforcetech

Bioforcetech has investigated the phosphorus content of biochar samples made at various locations where our systems are installed, as well as from biochar produced using our bench-scale pyrolysis unit using biosolids samples provided by wastewater treatment plants across the country. The **Table** shows the P content found in our testing, which was performed using standard IBI methodology,¹ in comparison with total P content reported in scientific pyrolysis studies.

Bioforcetech SSB	Total P (mg/g)
Installation #1: Sample 1	46.42
Installation #1: Sample 2	45.39
Installation #1: Sample 3	46.15
Installation #2: Sample 1	64.39
Installation #2: Sample 2	65.98
Installation #2: Sample 3	63.80
Installation #3: Sample 1	33.26
Client 1	55.30
Client 2	35.97
Client 3	59.38
SSB from the literature	Total P (mg/g)
Figueiredo et al. 2021	23.98
Figueiredo et al. 2021	34.01
Figueiredo et al. 2021	35.75
Figueiredo et al. 2021	37.50
Liu et al. 2019	85.00
Liu et al. 2019	90.00
Liu et al. 2019	98.00
Liu et al. 2019	106.40

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¹ The International Biochar Initiative (IBI) Laboratory Tests for Certification Program is a standardized testing regime that biochar producers use to demonstrate their products meet IBI's safety and quality criteria for soil use, analyzed by accredited laboratories following prescribed methods so results are reliable, comparable, and suitable for use in IBI biochar certification and labelling.

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