LIGNOCELLULOSIC AND POULTRY LITTER BIOCHARS AS A TWO-PRONGED APPROACH TO PLANT NUTRIENT REGULATION

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1. Keywords

Nutrients, Sorption, Biochar, Soil, Pollution

2. Highlights

- Poultry litter biochars act as a slow-release mechanism for plant nutrients.
- Lignocellulosic biochars immobilise excess plant nutrients in soil.
- In combination, they regulate nutrient concentrations to prevent water pollution.
- NPK leaching kinetics and sorption capacities, losses, & kinetics were determined.

3. Purpose

Nitrogen, phosphorous, and potassium (NPK) are added to soil in the form of fertilisers to enhance the growth of crops, but this intended function is also their hazard—excess fertilisers end up in waterways by way of runoff where they cause algae to grow faster than the ecosystem can handle. Algal blooms shade and kill submerged plants, whose decomposition alongside that of the algae itself consumes oxygen vital to the survival of all aquatic organisms. Some algal blooms also produce toxins that threaten human health. Nutrient pollution is thereby an existential threat to aquatic life and a serious risk factor with respect to water security and aquaculture. [1]

The House of Commons Environmental Audit Committee reported in 2022 that agricultural pollution is the most common driver of ecological damage to UK waterways. [2] Following this report, the UK Government introduced a legally binding target to reduce nitrogen and phosphorus loads from agriculture by 40% by 2038. [3]

While there are clear environmental and regulatory incentives to reduce agricultural pollution of plant nutrients, food security relies on the continued use of fertilisers to enhance land productivity. One solution is to slowly release nutrients to soil over time. Another is to immobilise excess nutrients in soil, releasing them only as required by crops. Combining these techniques ensures that the latter mechanism encounters only manageable excesses.

Poultry litter (PL), being readily available on farms, is itself widely used by farmers as a fertiliser, in some cases so excessively as to be responsible for severe nutrient pollution in nearby waterways. [4] When converted to biochar, PL is not only sterilised, neutralising the threat of pathogen pollution, but nutrient release is slowed, reducing the risk of nutrient pollution. Poultry litter biochars (PLB) can thereby be deployed as a slow-release fertiliser.

Conversely, lignocellulosic biochars (LCB), which contain substantially less inorganics than PLB, [4,5] can adsorb excess nutrients in soil owing to the naturally high surface area of their complex cellular structure. This allows them to act as a regulatory mechanism by adsorbing and desorbing nutrients in response to concentration gradients, immobilising excess nutrients in soil and releasing them only as needed.

In combination, PLB feeds a manageable amount of nutrients to soil, which is either used by crops, or immobilised by adsorption to LCB. If nutrients are not released fast enough as demand increases over the lifecycle of crops, excesses immobilised on LCB are desorbed in response to low soil concentrations. When crops are harvested and nutrient demands subside, remaining nutrients released from PLB are adsorbed to LCB.

This work aims to quantify the limits of this nutrient regulation system: (1) How quickly can LCB desorb nutrients in the absence of environmental excess? This requires determining the desorption kinetics of LCB. (2) For how long can LCB adsorb nutrients in the absence of crop demand? This requires determining the leaching kinetics of PLB, as well as the adsorption capacity and kinetics of LCB.

4. Materials and methods

PL and pine sawdust were pyrolysed in fixed-bed reactors at peak temperatures of 500, 600, and 700°C with standardised heating rates, residence times at peak temperature, and sweep gas compositions/flowrates.

Biochars were shaken at room temperature in deionised water with small samples regularly taken for analysis. LCBs were then shaken in PLB leachates to quantify sorption kinetics, with small samples regularly taken for analysis.

LCBs were repeatedly shaken in fresh PLB leachate (with the maximum nutrient concentration achieved), and then filtered to recover the treated leachate until its concentration no longer substantially decreased, in order to quantify adsorption capacity. This procedure was repeated with deionised water until nutrient concentration no longer increased to quantify sorption losses.

Nutrient concentrations of known solutions of model compounds were quantified by LC-MS, GC-MS, FTIR, and UV-vis. Results of this analysis were used to determine the most accurate and rapid method to quantify total NPK concentrations of leachates.

5. Results and discussion

While both LCB and PLB leach nutrients at a decreasing rate until a maximum value is reached, LCBs achieve a substantially lower maximum and subsequently begin to adsorb their own leached nutrients. Moreover, LCBs adsorb nutrients from PLB leachates until a minimum treated leachate concentration is reached, after which they begin desorbing these nutrients. Sorption rates correlate with real-time leachate concentrations. LCBs have a maximum adsorption capacity beyond which they are unable to adsorb more nutrients from PLB leachates. They are unable to desorb their full adsorption capacity.

Nutrient leaching rates of biochars, as well as adsorption capacities, sorption losses, and time-resolved adsorption-desorption curves of LCB were used to determine optimal ratios of LCB to PLB to minimise excess nutrient concentrations in soil under different levels of nutrient demand. Effects of peak pyrolysis temperatures on these ratios were evaluated.

6. Conclusions and perspectives

This work demonstrates the viability of a system of lignocellulosic and poultry litter biochars as a two-pronged approach to plant nutrient regulation for prevention of environmental nutrient pollution. Optimal pyrolysis conditions and biochar ratios for effective regulation of plant nutrients under different environmental conditions are suggested.

7. References

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