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Chemical properties of plant-based biochar to be used as soil fertiliser in Galicia (NW Spain)

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Abstract The excessive use of chemical fertilisers can cause soil acidification, depletion of soil quality, and biodiversity loss. Alternatively, biochar can improve crop productivity due to its ability to bind macronutrients and micronutrients and also adsorb various contaminants. However, the properties of the biochar depend among other factors on the material used to produce the biochar and the pyrolysis process. This study aims to evaluate the total nitrogen concentration of different types of biochar produced from forest plants to be used as fertiliser and amendment in acidic soils of Galicia (NW Spain). In this experiment, the biochar was produced from different tree fractions (branches, dry leaves, green leaves) of six tree species (*Pinus radiata* D. Don, *Pinus sylvestris* L., *Pinus pinaster* Aiton, *Betula alba* L., *Quercus robur* L., *Castanea sativa* Mill.) under different pyrolysis times (30, 60 and 120 minutes) at a temperature of 300°C. The results obtained showed that *Betula alba* L. and *Pinus sylvestris* L. increased the total nitrogen concentration in the biochar, independently of the tree faction. The same result was observed for *Quercus robur* L. when the branches and green leaves were used to produce biochar. Moreover, a pyrolysis time of 60 minutes increased the total nitrogen in the biochar, mainly in the case of *Pinus radiata* D. Don and *Pinus pinaster* Aiton. Therefore, the biochar produced from these tree species and fractions with a pyrolysis time of 60 minutes could be used as amendment and fertiliser in the Galician soils.

Keywords: conifers, broadleaves, soil amendment, pyrolysis, forest trees waste

1. Introduction

The European Commission intends to make Europe the first climate-neutral continent by 2050 (EC, 2019). Biochar can be considered a green technology that can play a big role in agricultural purposes as enhances water infiltration, water holding capacity, ionic exchange capacity, and nutrient availability in soil, which results in a reduction in chemical fertiliser use (Laird et al., 2010; Ayodele et al., 2009). Biochar is produced by the thermal decomposition of organic materials in a container with little or no oxygen, resulting in a carbon-rich product (Lehmann and Joseph, 2015).

In Galicia (NW Spain), forest areas cover about 60.5% of the total area (MAPA, 2020). In this region, the most common tree species included in the forest areas are *Pinus pinaster* Aiton, *Quercus robur* L. and *Eucalyptus globulus* Labill (Rodríguez et al., 2022). Therefore, the use of the different fractions (branches, litterfall, and green leaves) of these or other tree species as a biochar source could increase the opportunity for forest sustainable management in Galicia. Biochar properties, such as chemical composition and physical properties, can be influenced significantly by various factors, including temperature and pyrolysis time (Mukherjee and Zimmerman, 2013). However, it seems that the feedstock has a major impact on nutrient enrichment and the quality of the biochar (Cao et al., 2010). Authors such as Park et al. (2019) have found in their studies that different plant species can produce biochar with varying percentages of essential elements for plant growth, thereby affecting soil nutrient availability. Thus, when selecting a feedstock for biochar production, the desired properties must be considered.

Nitrogen (N) is an essential macronutrient for plant vegetative growth and development, playing a significant role in protein formation, chlorophyll, and DNA, as well as in the regulation of metabolic processes (Xiong et al., 2021). Adding biochar to the soil can increase the soil's ability to return N and other nutrients and reduce its loss through volatilization and leaching. This is due to the high surface area that the biochar gives which can be a habitat for the microorganisms which is the main reason to break down the organic matter and change it to organic available nutrients (Li et al., 2018; Jeffery et al., 2017). However, it is necessary to evaluate how the concentration of total N in the biochar is influenced by factors such as the temperature and time of pyrolysis when forest residues are used as a feedstock due to the lack of knowledge.

This study aims to estimate the total N concentration in the biochar produced from three different tree fractions (branches, litterfall, and green leaves) of six tree species (*Pinus radiata* D. Don, *Pinus sylvestris* L., *Pinus pinaster* Aiton, *Betula alba* L., *Quercus robur* L., *Castanea sativa* Mill.) under different pyrolysis time (30, 60, and 120 minutes) at a temperature of 300°C.

2. Materials and methods

In September 2021, the feedstock to produce biochar was collected from various forest plantations in Galicia (NW Spain). The feedstock was from three different tree fractions (branches, litterfall, and green leaves) of six tree species (*Pinus radiata* D. Don (Pr), *Pinus sylvestris* L.

(PS), *Pinus pinaster* Aiton (Pp), *Betula alba* L. (Ba), *Quercus robur* L. (Qr), and *Castanea sativa* Mill (Cs)).

Upon feedstock collection, the pyrolysis process to produce biochar was conducted on a muffle with ceramic crucibles containing the feedstock for 30, 60, and 120 minutes at a temperature of 300°C. The resulting biochar was ground using an agate mortar, and pestle and stored in a plastic-sealed bag (Gonzaga et al., 2017). To ensure the experiment's validity, three replicates of biochar for each type of feedstock were produced.

In the laboratory, the total N concentration was determined in the feedstock before the pyrolysis process (initial) and in the biochar after the pyrolysis process for each tree species and fraction using LECO CNS-2000 instrumentation (Kowalenko and Grant, 2001).

The statistical analyses used in this study included both the LSD (Least Significant Difference) and ANOVA (Analysis of Variance) tests, which were performed using SAS software. The LSD test was specifically used to differentiate the means when the ANOVA test results were determined to be significant.

3. Results

In this study, the total N concentration in the biochar was significantly affected by the different tree species used to produce the biochar in each pyrolysis time and tree fraction ($p<0.05$) (Figure 1).

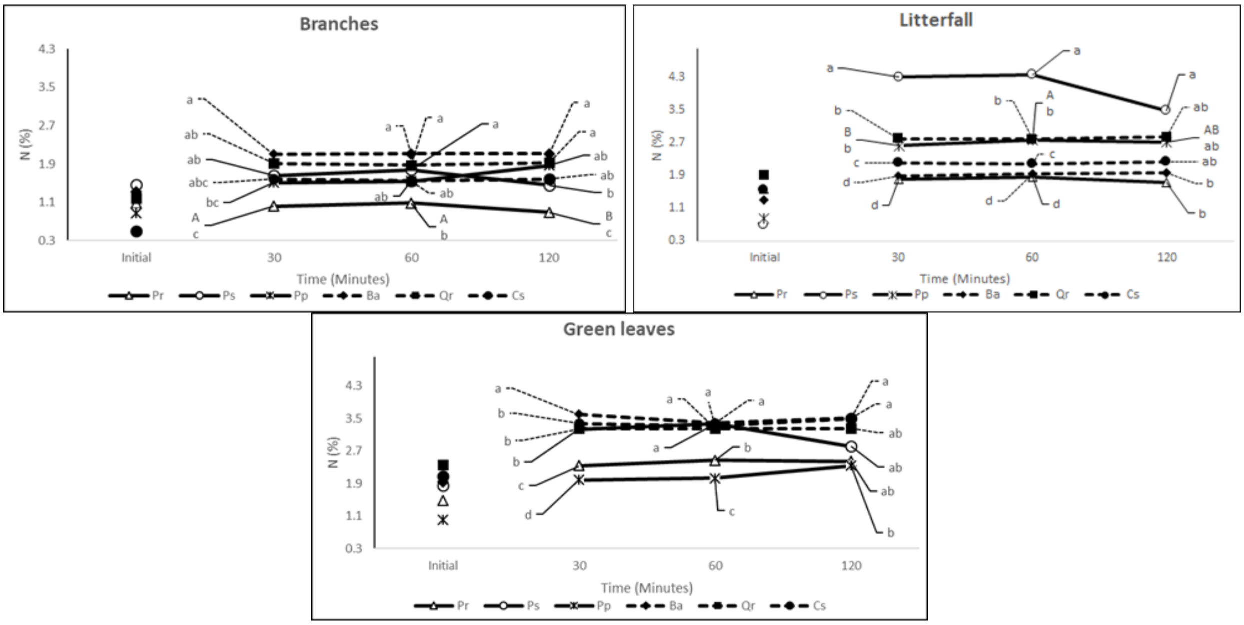

Figure 1. The total N concentration (%) in the biochar produced from branches, litterfall and green leaves of different tree species (PR: *Pinus radiata* D. Don, PS: *Pinus sylvestris* L., PP: *Pinus pinaster* Aiton, BA: *Betula alba* L., QR: *Quercus robur* L., CS: *Castanea sativa* Mill) under different pyrolysis timings (30, 60 and 120 minutes). The initial total N concentration indicates the N concentration in each tree species and fraction before the pyrolysis process. In each tree fraction, different lowercase letters indicate significant differences among tree species under the same pyrolysis time and different uppercase letters indicate significant differences among pyrolysis times within the same tree species.

In the case of the branches tree fraction, after 30 minutes of pyrolysis, biochar produced from Ba had a higher total N concentration than biochar produced from Pp and Pr, while Ps and Qr implied biochar with a higher N concentration than Pr. However, after 60 minutes of pyrolysis, biochar produced from Ps, Ba, and Qr had higher N concentrations than biochar produced from Pr. Moreover, after 120 minutes of pyrolysis, Ba and Qr also produced biochar with higher N concentrations than Pr and Ps, and biochar produced from Pr had a lower N concentration compared to all other species.

In the litterfall tree fraction, after 30 and 60 minutes of pyrolysis time, the total N concentration in the biochar produced from Ps was higher compared to all the other species. Moreover, the total N concentration in the biochar produced from Pp and Qr had a higher amount of N compared to Cs after 60 min, which are all subsequently higher than Pr and Ba. A positive effect of Ps on the total N concentration in the biochar was also observed compared to Ba and Pr after 120 minutes of pyrolysis time.

Finally, the total N concentration in the biochar produced from the green leaves tree fraction varied significantly. Specifically, after 30 minutes of pyrolysis when biochar produced from Ba had a higher N concentration than biochar produced from all the other tree species. Moreover, for this pyrolysis time, the total N concentration in the biochar produced from Qr, Cs, and Ps was higher compared to Pr, and Pp while Pr had a higher N concentration than biochar produced from Pp. After 60 minutes, biochar produced from Ps, Ba, Qr, and Cs had higher total N concentrations than biochar produced from Pr and Pp. Additionally, biochar produced from Pr had a higher total N concentration than Pp. After 120 minutes of pyrolysis, biochar produced from Ba and Cs had higher total N concentrations than biochar from Pp.

Moreover, the total N concentration in biochar produced from the branches of Pr and the litterfall of Pp was significantly affected by the pyrolysis time ($p<0.05$). In the case of the biochar produced from Pr branches, the total N concentration in the biochar after 30 and 60 minutes of pyrolysis time was higher compared to a pyrolysis time of 120 minutes. However, in the biochar produced from Pp litterfall, the total N concentration after 60 minutes was higher compared to 30 minutes.

4. Discussion

The results of this study showed that the total N concentration in the biochar produced from the tree branches ranged from 0.89% to 2.11%. In the biochar produced from litterfall, the total N concentration ranged from 1.7% to 4.3% and when the biochar was produced from green leaves, the total N ranged from 1.9% to 3.5%. According to the literature review, it was found that the total N concentration in the biochar produced from different plants (*Pinus sylvestris* L., *Pinus taeda* L., cotton straw, and rice husk) ranged from 0.2% to 5% which is in parallel with the results obtained in this study (Jia et al., 2018; Kulczycki et al., 2020; Novak et al., 2015). Moreover, in other studies in which biochar was produced from sewage sludge, the total N concentration varied from 0.2% to 5.9% (Regkouzas et al., 2019). This range is also similar to the ranges reported in this study. However, it is important to be aware that the biochar produced from sewage sludge can be considered riskier than the biochar produced from plant residues due to sewage sludge can present pathogens and heavy metals in high concentrations (Gherghel et al., 2019).

On the other hand, authors such as Jia et al. (2018) mentioned in their studies that the type of feedstock and the feedstock residence time in the muffle significantly affect the total N concentration in the biochar. This result was also observed in this study because the total N concentration in the biochar was different depending on the tree species and the fractions used to produce the biochar. In this context, the tree species that increased more the total N concentration in the biochar were generally Ba, and Ps, independently of the tree faction; compared to the other species. Moreover, Qr also increased the total N concentration when branches and green leaves were used to produce biochar. The different N concentrations found in the biochar produced from these tree species could be explained by their high N concentration before being used as material to produce biochar (Leng et al., 2020). Thus, the total N concentration before the pyrolysis process in Ba (branches: 1.31 %, litterfall 1.31 % and green leaves: 1.94 %), Ps (branches: 1.46 % litterfall: 0.675 % and green leaves: 1.85 %) and Qr (branches: 1.19 %, litterfall: 1.9 % and green leaves: 2.36 %) was generally higher than in other tree species such as Pp (branches: 0.86 %, litterfall: 0.84 % and green leaves: 1.01 %). Moreover, it is important to be aware that certain amino acids, like arginine, contain amide groups that can be easily transformed into gas by-products NH_3. When nitrogen-containing components build up, they create more N-functional groups, which ultimately increases the amount of N in the resulting biochar (Leng et al., 2020). This process may explain the high total N concentration observed in the biochar produced from some tree species that before the pyrolysis process had low N such as the branches of Cs and the litterfall of Pp.

Finally, when the effect of the pyrolysis time on the total N concentration in the biochar is evaluated, it is important to take into account that the change in N concentration through time can be attributed to the feedstock decomposition level (Gaskin et al., 2008). In general, an excessive pyrolysis time leads to decreased N concentration in biochar due to the N volatility (He et al., 2023), as was observed in this study when biochar was produced from the branches of Pr after 120 minutes of pyrolysis. However, an insufficient pyrolysis time can result in a low total N concentration, as was found in this experiment in the case of the litterfall of Pp after 30 minutes of pyrolysis time. Therefore, this finding suggests that a pyrolysis time of only 30 minutes was inadequate for the complete decomposition of the feedstock, leading to reduced N concentration. In previous studies, authors such as Tsai et al. (2018) have also reported the impact of varying pyrolysis times on the total concentration of N in biochar produced from cocoa pod husk feedstock, with a pyrolysis temperature of 370°C.

5. Conclusion

The results obtained in this study showed that *Betula alba* L. and *Pinus sylvestris* L. increased the total N concentration in the biochar, independently of the tree faction. The same result was observed for *Quercus robur* L. when the branches and green leaves were used to produce biochar. Moreover, a pyrolysis time of 60 minutes increased the total N concentration in the biochar, mainly in the case of *Pinus radiata* D. Don and *Pinus pinaster* Aiton. Therefore, the biochar produced from these tree species and fractions with a pyrolysis time of 60 minutes holds a high potential for application as a soil amendment and fertiliser in the Galician region. The utilization of such biochar can contribute to enhancing soil quality and fertility, thereby promoting sustainable agricultural practices.

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