Effect of Pyrolysis Temperature and Time on Salicornia Biochar Yield and Physicochemical Properties (Postprint)

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Abstract

Xinjiang is the largest salt-affected soil distribution area in China, with extremely abundant halophyte resources that possess strong salt absorption and accumulation capabilities. Using Salicornia europaea as raw material, this study investigated the effects of pyrolysis temperature and duration on the biochar yield and physicochemical properties of Salicornia europaea. The results demonstrated that pyrolysis could effectively increase the pH, EC (electrical conductivity), and ash content of Salicornia europaea, with the biochar pH reaching a maximum of 10.37, and the biochar ash content increasing by 57.51%~110.98% compared to that of the raw Salicornia europaea. At 300~600 °C, as the pyrolysis temperature increased, the biochar pH, EC, and ash content increased significantly, while the yield decreased; the water-soluble Ca2+ and Mg2+ contents in biochar decreased with temperature (400 °C), while low-valence ions such as Na+ and K+ were enriched; the total potassium and total phosphorus contents in biochar gradually increased with temperature, whereas the total carbon and total nitrogen contents decreased. With increasing pyrolysis time, the pH, EC, and ash content gradually increased, the carbon content gradually decreased, and the water-soluble ion content increased. Based on the physicochemical properties of the biochar, a pyrolysis time of 2 h was identified as the most suitable duration. This study can provide a new approach for the selection of raw materials for biochar amendment of acidic soils and the optimization of plant biochar preparation processes.

Full Text

Preamble

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1 Materials and Methods

1.1 Experimental Materials

Salicornia europaea biomass was collected from the Fukang Desert Ecosystem Observation and Experiment Station, Chinese Academy of Sciences. The samples were dried at 65°C to constant weight, then ground and sieved to 2–3 cm fragments. The prepared biomass was pyrolyzed in a muffle furnace (model SX2-4-10) at four temperature levels: 300°C, 400°C, 500°C, and 600°C, each for 2 hours. Additionally, to examine the effect of pyrolysis duration, separate samples were pyrolyzed at 500°C for 1 hour, 2 hours, and 3 hours. The basic physicochemical properties of the raw Salicornia europaea material are presented in .

Properties of Salicornia europaea

1.2 Experimental Methods

1.2.1 Biochar Preparation and Basic Property Analysis
Biochar yield was calculated as the mass percentage of the final product relative to the initial dry biomass. The pH and electrical conductivity (EC) were measured using a 1:5 (w/v) water extract after shaking for 30 minutes. Ash content was determined by combusting the biochar at 500°C for 2 hours. Water-soluble Na and K concentrations were measured by flame photometry, while Ca^{2} and Mg^{2} were analyzed using inductively coupled plasma optical emission

spectrometry (ICP-OES, model 735). Chloride and sulfate concentrations were determined by ion chromatography (ICS-5000).

1.2.2 Ion Content Analysis

Water-soluble ion contents were extracted and analyzed as described in section 1.2.1.

1.2.3 Total Nutrient Analysis

Total nitrogen (TN) was measured using the Kjeldahl method. Total phosphorus (TP) was determined by molybdenum-blue colorimetry after acid digestion. Total potassium (TK) was analyzed by flame photometry following acid extraction.

1.2.4 Statistical Analysis

All data were processed using SPSS 19.0 software. One-way ANOVA was performed to assess treatment effects, with significant differences identified at $P < 0.05$. Graphical representations were generated using SigmaPlot.

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2 Results

2.1 Effects of Carbonization Temperature on Biochar Properties

As shown in , increasing pyrolysis temperature from 300°C to 600°C significantly reduced biochar yield from 64.81% to 46.02% ($P < 0.05$). Concurrently, pH, EC, and ash content increased markedly with temperature. The pH rose from 7.19 to 10.37, while ash content increased from 36.15% to 76.27%, representing a 57.51%-110.98% enhancement relative to the raw material.

2.1.1 Effects on pH, EC, and Ash Content

The pH values of biochar produced at different temperatures ranged from 5.96 to 10.37, showing a significant positive correlation with pyrolysis temperature ($P < 0.05$). When the temperature exceeded 500°C, the pH increase became more pronounced. Similarly, EC values increased progressively from 1.24 to 2.40 $mS \cdot cm^{1}$ across the temperature gradient ($P < 0.05$). Ash content exhibited the most dramatic response, increasing from 36.15% at 300°C to 76.27% at 600°C.

2.1.2 Effects on Ion Content

Water-soluble ion concentrations varied significantly with pyrolysis temperature ([Figure 1: see original paper]). The contents of water-soluble Na , K , and Cl increased substantially when temperature rose from 300°C to 600°C, with maximum values of 42.61%, 48.14%, and 46.98% respectively observed at 300°C. In contrast, water-soluble Ca^{2} and Mg^{2} concentrations decreased significantly at temperatures 400°C. The sulfate content showed no significant difference between treatments ($P > 0.05$).

Total nutrient analysis revealed that total Ca content peaked at 400°C (2.658 $g \cdot kg^{1}$), while total N content decreased with increasing temperature, ranging from 0.613 to 0.925 $g \cdot kg^{1}$ across the temperature gradient—still 37.45%-5.61%

higher than the raw material (0.980 g · kg ^{1}). Total P and total K contents increased significantly with temperature ($P < 0.05$), reaching maximum values of 23.213 g · kg ^{1} and 11.947 g · kg ^{1} respectively at 600°C, which were 32.27%-104.47% higher than the raw material.

2.2 Effects of Carbonization Time on Biochar Properties

2.2.1 Effects on Yield, pH, EC, and Ash Content

Extending pyrolysis duration from 1 to 3 hours at 500°C significantly affected biochar properties (). While yield decreased from 49.17% to 45.72%, pH, EC, and ash content showed gradual increases. The pH rose from 10.28 to 10.39, EC increased from 2.08 to 2.22 mS · cm ^{1}, and ash content increased from 62.78% to 74.77%.

2.2.2 Effects on Ion Content

Water-soluble ion concentrations responded differently to pyrolysis duration (). Na and K contents decreased with longer pyrolysis time, with the highest values (19.129 g · kg ^{1} and 5.903 g · kg ^{1} respectively) observed at 2 hours. Ca^{2} content showed no significant difference between treatments ($P > 0.05$), while Mg^{2} content was highest at 2 hours (17.489 g · kg ^{1}). Cl content decreased significantly with time, whereas SO ^{2} content increased.

2.2.3 Effects on Total Nutrient Content

Total N, P, and K contents were significantly affected by pyrolysis duration ($P < 0.05$). Total N content decreased from 6.100 g · kg ^{1} at 1 hour to 5.588 g · kg ^{1} at 3 hours. Total P content increased with time, reaching 1.103 g · kg ^{1} at 3 hours. Total K content was highest at 2 hours (25.58 g · kg ^{1}), showing a 27.15% increase compared to 1 hour treatment.

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3 Discussion

The results demonstrate that Salicornia europaea-derived biochar possesses unique physicochemical characteristics that make it suitable for soil amendment applications. The high ash content (up to 76.27%) and alkaline pH (up to 10.37) indicate strong potential for neutralizing acidic soils. The enrichment of water-soluble Na and K during pyrolysis, coupled with the retention of essential nutrients (P, K), suggests that this halophyte biochar could serve dual functions: improving soil fertility while managing saline conditions.

The inverse relationship between pyrolysis temperature and biochar yield is consistent with established thermal decomposition principles. The optimal pyrolysis conditions identified in this study—500°C for 2 hours—represent a compromise between maximizing nutrient retention and minimizing energy costs. At temperatures exceeding 400°C, the volatilization of organic compounds leads to increased porosity and surface area, which enhances the biochar' s cation exchange capacity and nutrient retention capabilities.

Previous studies have reported similar trends in biochar properties derived from various feedstocks. The high salt content in Salicornia europaea, particularly NaCl, contributes to the elevated EC values observed in the biochar products. This characteristic may be advantageous for reclaiming sodium-affected soils but requires careful consideration when applying to salt-sensitive crops.

The significant increase in total P and K contents with pyrolysis temperature suggests that these nutrients become more concentrated in the biochar matrix through volatilization losses of other components. However, the decrease in total N at higher temperatures indicates potential nitrogen loss through ammonia volatilization and other gasification processes, which should be considered when targeting nitrogen-enriched biochar products.

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Note: Figure translations are in progress. See original paper for figures.