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Project title: Improving Soil FERtility in Arid and semi-arid regions using Local organic DAte palm residues

D4-3 Report on the improvement of the physico-chemical and microbiological properties of the optimized organic amendments

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Summary

Biochar produced from date palm residues releases significant amounts of cations, such as calcium, potassium, magnesium, and sodium, when in contact with water. To mitigate this, rinsing biochar before its application to soil is recommended. Sodium retention by the biochars was consistently low, at about 15–20%, regardless of the oxygen levels used during pyrolysis. While biochars produced with oxygen showed slightly better sodium adsorption than those made without oxygen, the differences were minimal. The increase in specific surface area with oxygen presence did not significantly improve sodium retention, indicating that other factors, such as porosity and surface functional groups, also play important roles. Although biochar made from date palm residues has potential to combat soil salinization, its limited sodium retention capacity reduces its effectiveness. Following these studies, a design of an artisanal biochar device that can be built and used by farmers was proposed.

Compost made from date palm leaves and sheep manure demonstrated superior performance, with balanced nutrient content, high germination rates, and a stable carbon-to-nitrogen ratio. Poultry manure compost showed high potassium and nitrogen levels but had reduced germination rates, suggesting potential phytotoxicity. Compost made with sewage sludge was mature and had a low carbon-to-nitrogen ratio, but its potassium content was lower. Compost from leachate exhibited slower organic matter degradation and lower stability, limiting its agronomic value. Electrical conductivity levels were high in all composts, posing potential salinity risks due to organic matter mineralization and the salinity of water used during composting. According to this results, a bioreactor was designed to accelerate the composting process. It has been the subject of a patent application filed with the Algerian National Institute of Intellectual Property.

Compared to ASOC composts, Palm compost had higher nitrogen content and better organic matter stability, while ASOC composts were richer in phosphorus and had a higher mineral content. Biochar from date palm residues had high porosity and organic matter content, with limited microporosity and macroporosity. Both biochar and compost showed high pH and electrical conductivity, which could pose challenges in saline or alkaline soils, though these properties are unlikely to negatively impact soil fertility.

Compost amendments increased bacterial and fungal abundances, with bacterial growth favored due to the low carbon-to-nitrogen ratio. Ammonia-oxidizing archaea abundance increased with all amendments except urea, while ammonia-oxidizing bacteria were most abundant in soils amended with compost. Compost significantly enhanced the abundance of denitrifying gene communities, promoting efficient nitrate conversion to nitrogen gas. Biochar alone had a minimal effect on denitrifying communities but played a role in reducing nitrous oxide emissions and influencing microbial dynamics.

Overall, biochar and compost derived from date palm residues show promise for agricultural applications. Compost, particularly when combined with sheep manure, offers stability, nutrient richness, and microbial benefits. Biochar can aid in mitigating soil salinization but requires optimization to improve its retention capacity and reduce salinity risks.

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1 Introduction

One of the specific objective of the ISFERALDA project is to develop innovative organic amendments (OA) for crops in oases by recycling date palm residues, which can be considered as an agricultural waste. Date palm is widely cultivated in Tunisia and Algeria. An OA based on this abundant local resource would therefore represent a durable solution that is widely adaptable to a large part of these countries. Its realization would create local employment and develop local economy. Moreover, its application would improve the quality of a large part of the soils in these regions.

Several studies have therefore been carried out to optimize the management of date palm residues. A study was carried out to improve the production and quality of date palm compost and another was carried out to test the influence of the oxygen content in the air during pyrolysis and therefore the production of date palm leaf biochar. Another study was performed in order to characterize precisely and analyse the data of the OA used during the WP5. In addition, another study on the influence of selected OAs on microbial communities having a role in the nitrogen cycle in the soil will be presented in this report.

This report will therefore be divided in five parts according to the different studies performed in that work package.

2 Influence of the presence of oxygen during the production of date palm biochar[1]

Pyrolysis temperature is one of the factors that determine the properties of biochar. Low temperature is favorable for the preparation of biochar rich in polar functional groups, while high temperature promotes pore development and often results in biochar with high specific surface area (Chen et al. 2015). So far, most laboratory studies on the regulation of surface and adsorption properties of biochar have focused on raw material selection and temperature adjustment.

In most published studies, biochars are produced by pyrolysis in an inert atmosphere consisting exclusively of nitrogen. Biomass pyrolysis can also be carried out in an atmosphere with limited oxygen content. The use of oxygen is closer to a more natural, or artisanal, method, since the formation of char by natural fires and artificial combustion of biomass is often exposed to air. Furthermore, the introduced air can reduce the energy cost of biochar manufacturing (Xiao and Pignatello 2016; Gil-Lalaguna et al. 2014). This air activation has been used to introduce more oxygen-containing functional groups into the carbons, and has been validated as a potential strategy to improve porosity, including mesoporosity, and adsorption of organic contaminants (Xiao et al. 2018; Dawson et al. 2003). However, in most studies, the exact oxygen content for biochar manufacturing remains unknown. In this study, the influence of oxygen content during pyrolysis of date palm residues on the porosity and adsorption capacities of biochars was determined. For this, date palm residues were pyrolyzed at the same temperature (450 °C) under nitrogen flow, but with different oxygen contents: 0%, 1%, 3%, 5% and 7%. The porosity of the different biochars and their adsorption and desorption capacity with respect to sodium was then measured.

2.1 Material and methods

2.1.1 Biochar production

The residues that are used to produce biochar were the rachis of dry date palm leaves collected in Murcia region (Spain). The pyrolysis was performed at ENSTIB (Ecole Nationale Supérieure des Technologies et Industries du Bois, Epinal, France) in collaboration with LERMAB (Laboratoire d'E tudes et de Recherche sur le Materiau Bois, Lorraine University). The residues were first dried at 90 °C for 48 h. Pyrolysis time was 2 hours at 450 °C after pre-heating to 150 °C, with the temperature rising at a rate of 5 °C per minute up to 450 °C. Five different biochars were produced under N_2 flux with different proportions of O_2: 0, 3 and 7%, respectively BC0, BC3 and BC7.

2.1.2 Porosity measurements

Mercury intrusion porosimetry (MIP) analyses were performed in triplicate with a Micrometrics AutoPore IV 950 porosimeter to determine the total porosity and pore size

[1] A part of this study is published in the following paper: M. Ponthieu, J. Beucher, A. Guillaneuf, E. Le Guyader, V. Miconnet, M. Gommeaux, R. Amadou Guimbari, M. El Mazlouzi, B. Marin, and X. Morvan, 2025. Reactivity towards Na of biochars produced from date palm residues with different oxygen proportions during pyrolysis. Accepted in the proceedings of the International Conference on the Impacts of Soil Amendments on Dryland Agro-Ecosystems (ISADAE-2024), Reims, 28-30/10/2024. Pub IOP Science- IOP Conference Series: Earth and Environmental Science

distribution of the different unground biochars (Figure 1). This technique allows quantification of pore entrance diameter over a wide range of porosity.

The internal porosity of raw biomass and biochar was measured according to the following equation:

$$\text{Porosité (\%)} = 1 - \frac{\rho b}{\rho s} = \frac{\rho s - \rho b}{\rho s} \times 100$$

where ρb represents the density of the material and ρs the density of the skeleton, expressed in g.cm-3.

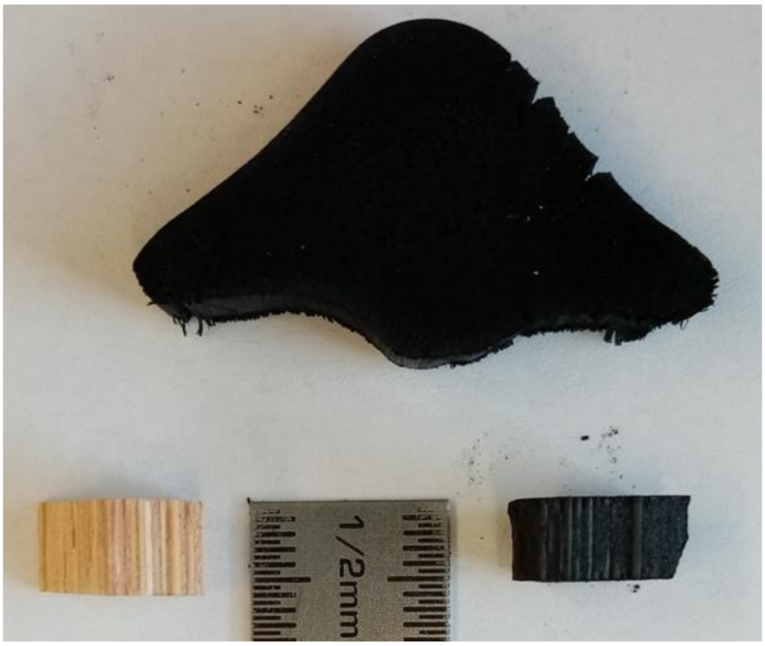

Figure 1 : Samples of date palm rachis before and after pyrolysis (Le Guyader, 2024)

2.1.3 Sodium Adsorption / Desorption experiments

2.1.3.1 Biochar mineralisation

Due to previous results, sodium adsorption / desorption experiments were performed on only three biochars: BC0, BC3 and BC7.

Biochars were dried at 105 °C to remove water then placed in an oven at 550 °C for 8 h. After the loss on ignition step, 0.25 g of ash was mineralised with a mixture of HCl and HNO3 (3.5 ml HCl 35% + 1.2 ml HNO3 70% + 7 ml HNO3 10%). The mineralisation step was performed in triplicate. After samples digestion, Ca, K, Mg and Na concentrations were measured using inductively coupled plasma optical emission spectrometry (ICP-OES, Thermo Scientific). The physisorption of dinitrogen at 77 K was performed at Institute Jean Lamour (University of Lorraine) on the biochars <200 µm using Micromeritics ASAP2020 adsorption apparatus. The samples were outgassed for 12 h at 350 °C before analysis. The specific surface area (SSA) was calculated using the Brunauer-Emmett-Teller (BET) method, completed with the Rouquerol correction.

2.1.3.2 Rinse / Adsorption / Desorption experiments (part of Ponthieu et al., 2025)

To avoid the release of Na present in the biochar during the adsorption/desorption experiments, duplicate samples of each biochar were rinsed until the amount of Na released was considered negligible. The rinses were performed with 10 g of biochar mixed with 200 mL of ultrapure water and shaken for 4 hours. The suspension was then centrifuged for 30 minutes at 3500 rpm, after which around 150 mL of supernatant was removed and for the next rinse, 150 mL of ultrapure water was added, then the same protocol was repeated. Five rinses were performed. Finally, the biochar samples were dried in an oven at 65 °C.

The rinsed biochars were used for the adsorption experiments performed in triplicate. For each experiment, 0.75 g of biochar was added to 30 mL of NaCl solution. Five Na concentrations were used: 45, 175, 350, 700 and 1300 mgNa.L-1. A control experiment was also carried out without the addition of Na to estimate the release of Na under the conditions of the adsorption experiments. The suspensions were shaken for 24 h and then filtered using a vacuum pump with 0.7 µm glass fibre filters. The filtrates were collected for analyses. The biochars were dried in an oven at 65 °C and then used for the desorption experiments.

The desorption experiments were performed for the 3 biochars, on the triplicates on which the adsorption experiments were conducted. For that, 0.5 g of dried biochar was added to 20 mL of ultrapure water. The protocol was similar to the one followed for the adsorption experiments with shaking for 24 h, then filtration.

The concentrations of Ca, K, Mg and Na were analysed in the filtrates obtained after the adsorption experiments, using ICP-OES. The pH values were measured in the filtrates after the adsorption experiments. They were 8.36 ± 0.02 for BC0 and of 8.69 ± 0.05 for BC3 and BC7 whatever the NaCl concentration used.

2.1.4 Statistical analyses

Statistical analyses were conducted to test the effect of biochar type on biochar properties and measured parameters, using one-way analysis of variance in R (version 4.3.1). Post-hoc comparisons were made using the LSD test to identify differences among biochar types.

2.2 Results and interpretation

2.2.1 Biochar production

Biochar yields relative to initial biomass are presented in Table 1. As expected, the biochar yields are around one third of the starting biomass whatever the produced biochar. There are no significant differences in biochar yields according to the percentage of oxygen in the atmosphere during pyrolysis.

Table 1 : Biochar yields for the three produced biochars

	Starting biomass (kg)	Biochar mass (kg)	Biochar yield
BC0	1,5	0,498	33 %
BC3	1,5	0,529	35 %
BC7	1,5	0,517	34 %

2.2.2 Biochar characterisation (part of Ponthieu et al., 2025)

The three biochars have basic pH, with a mean value of 9.6 as observed previously by Sizirici et al. (2021) with a pH slightly lower for BC0 compared to BC3 and BC7 (Table 2). The SSA measurements evidenced an increase in the SSA with the increasing quantity of O_2 during pyrolysis, results in agreement with previous observations. Zhu et al. (2018) worked at 700°C with an air flux during thermal treatment ranging from 0 to 90 ml/min which corresponds to O_2 proportions of around 0 to 6%. They demonstrated an increase in the volume of mesoporosity and the value of the SSA with the presence of O_2 between 0 and approximately 3-4%. Amounts of O_2 above 3-4% no longer increased the SSA of biochars.

Table 2 : Biochars characterisation

	pH (1st rinse)	*Specific surface area ($m^2.g^{-1}$)*	*Total Ca $g.kg^{-1}$*	*Total K $g.kg^{-1}$*	*Total Mg $g.kg^{-1}$*	*Total Na $g.kg^{-1}$*
BC0	8.5	13.5	26.8+/-0.4	26.0+/-0.9	12.6+/-0.2	2.80+/-0.01
BC3	10.1	32.4	17.2+/-0.3	22.8+/-0.4	9.8+/-0.1	1.46+/-0.03
BC7	10.1	73.2	21.2+/-0.2	21.8+/-0.3	11.0+/-0.1	1.29+/-0.00

Total Ca, K, Mg and Na concentrations are higher in BC0 than in BC3 and BC7. To our knowledge, the few studies that have looked at the impact of the presence of O_2 during pyrolysis on the properties of the biochars produced have not worked with date palm residues and have not looked at the impact on the chemical composition of the biochars. The total concentrations measured in this study are of the same order of magnitude as those measured by Usman et al. (2015) working on biochars derived from date palm residues. The main difference is the calcium concentrations, which are twice higher in their study for biochars produced at 400 and 500 °C. Awan et al (2021) studied the chemical composition of four biochars of different origins (wheat straw, lodge pine, Kentucky bluegrass and hemp stalks) and highlighted a significant variability of their composition, with Ca concentrations varying from 0.5 to 17.9 g.kg-1, K from 2.2 to 24.2 g.kg-1, Mg from 2.5 to 8.2 g.kg-1 and Na from 0.3 to 26.1 g.kg-1, depending on the nature of the feedstock. The results obtained in this study for Ca, K and Mg are higher than or correspond to the high values of variability presented in the article of Awan et al. (2021). Ippolito et al. (2020) have shown in their review that the chemical composition of biochars is highly variable and is mainly influenced by the feedstock used.

2.2.3 Biochar porosity

The mean values of mercury intrusion and porosity as a function of the pore size radius are presented in Figure 2 and Figure 3. BC0 has a higher volume of macroporosity than the two other biochars. Indeed, a clear peak appears on the Figure 3 at the pore size radius of 100 µm. However, that kind of porosity is useless for available water capacity (AWC), as pores with radius between around 10 and 0.1 µm are useful for AWC. Regarding the total porosity, no significant differences can be seen between the 3 biochars, the mean total porosity ranged between 68 and 70% for the three biochars, with no significant tendances (Figure 3).

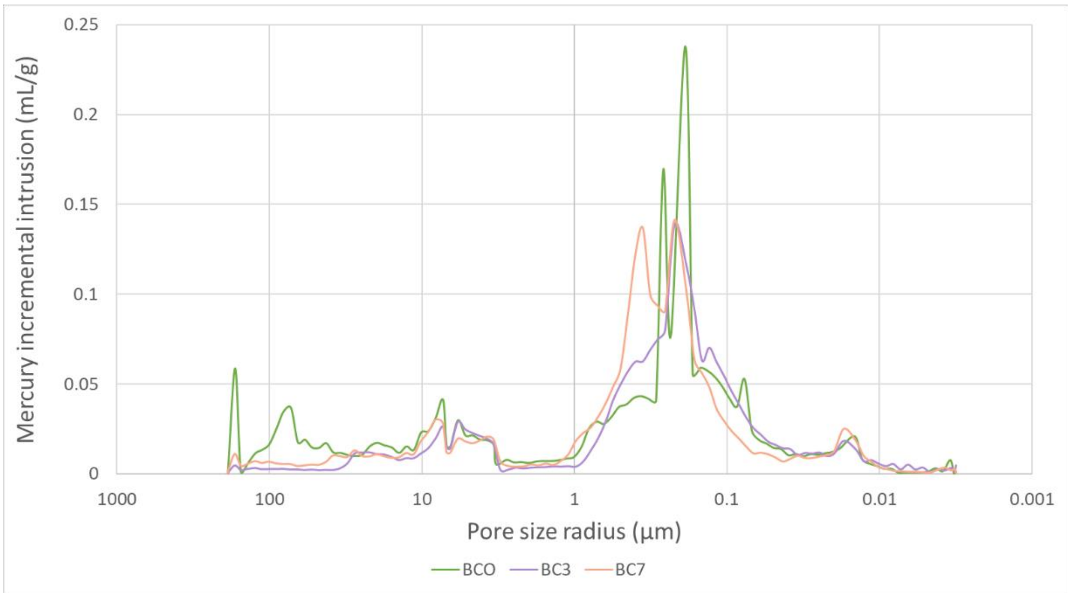

Figure 2 : Pore size distribution as a function of pore size by mercury intrusion porosimetry for 3 biochars produced with different atmospheric oxygen contents

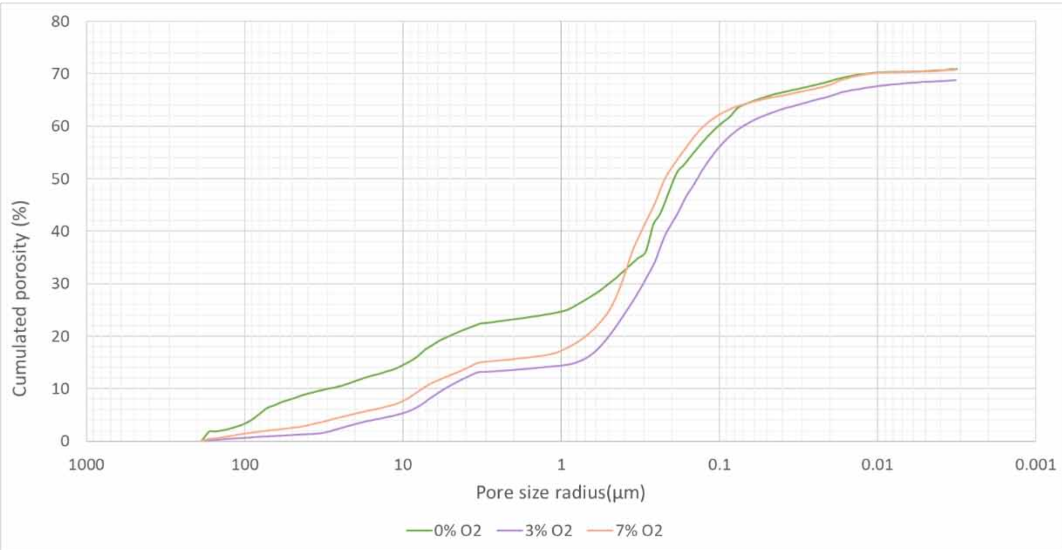

Figure 3 : Cumulative porosity as a function of pore size by mercury intrusion porosimetry for 3 biochars produced with different atmospheric oxygen contents

2.2.4 Reactivity towards Na of biochars (part of Ponthieu et al., 2025)

2.2.4.1 Biochar rinse

Only the results of the 1st rinse are shown in Figure 4, highlighting a difference between the 3 biochars. The biochar produced in the absence of oxygen (BC0) has the highest levels of Ca, K, Mg and Na in the rinse water which is linked to the higher total content of these 4 elements in this biochar. Figure 4b shows that the proportions extracted are slightly higher for BC0 compared to BC3 and BC7 for Ca, Mg and K. Whatever the biochar considered, the most abundant element in rinse water was K.

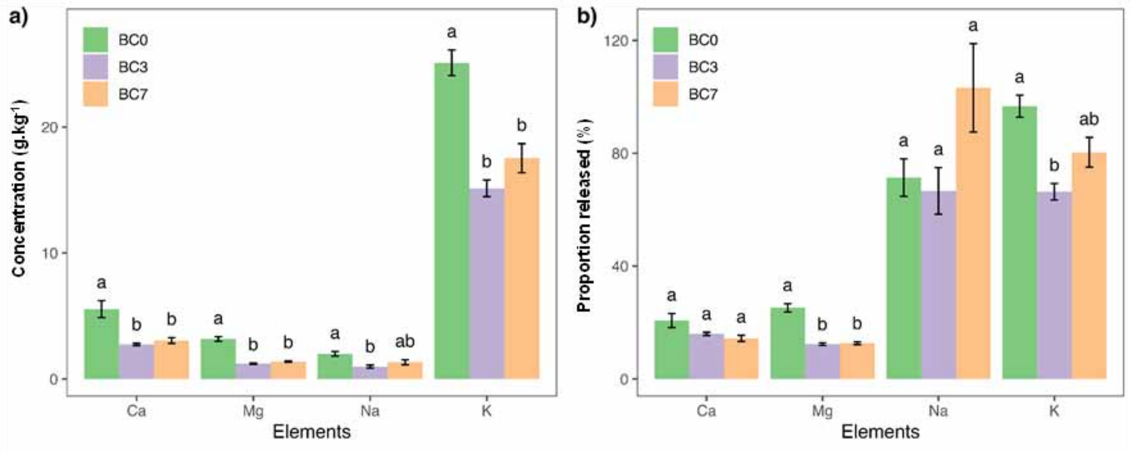

Figure 4 : Concentrations measured in the solution of the 1st rinse expressed in g.kg-1 of biochar (a) and as a percentage of total concentrations (b). Bars indicate standard deviation of two replicates. Different letters indicate statistically significant differences between biochar types, as determined by the LSD test at p < 0.05. (Ponthieu et al., 2025)

Md Som et al. (2012) worked with biochar produced from palm fronds of oil palm tree. They observed the same trends, with K levels much higher than Ca, Mg and Na levels. Figure 1b evidenced that the four elements studied behave differently during rinsing. Between 60% and 100% of Na and K were extracted during the 1st rinse, whereas only between 10 and 20% of Ca and Mg were extracted. These two divalent cations were therefore more strongly retained within the biochar than the monovalent cations K and Na, which were released as soon as they came into contact with water.

These results showed that the addition of biochar produced from date palm residues to the soil could lead to a significant release of cations into the soil when in contact with water. Nguyen *et al* (2022) reached the same conclusion for biochars produced from rice husk, corn stalks, longan branches and coconut coir. They recommended rinsing biochars before applying them to the soil. The release of significant quantities of cations could pose a problem in soils already affected by salinization processes.

Concentrations in the rinse water decreased with each rinse, reaching an average of 0.073 ± 0.019 g.kg^{-1} of biochar for Na at the 5th rinse for the 3 biochars studied. This concentration is considered sufficiently low compared to the concentrations of Na added for the adsorption experiments (levels between 1.83 and 52.7 g.kg^{-1}).

2.2.4.2 Na adsorption

The adsorption experiments were carried out with 5 different concentrations of Na ranging from 45 mg.L^{-1} to 1300 mg.L^{-1}. Despite rinsing, significant concentrations of Na were measured in the control experiment (between 0.2 and 0.4 g.kg^{-1}). These concentrations were taken into account when calculating the quantity of Na adsorbed. The concentration of adsorbed Na corresponds to the concentration of added Na minus the concentration of Na measured in the solution after 24 hours of agitation corrected for the concentration measured in the control experiments (without Na). The amount of Na adsorbed on the three biochars increased with the concentration of Na in the solution (Figure 5a), but the proportion of adsorbed Na calculated in relation to the total amount of Na added remained more or less constant at around 15-20%.

A fairly high variability in Na concentrations adsorbed on BC0 is observed, compared with the other two biochars. Nevertheless, according to statistical tests, for the lowest Na concentrations in solution (45 and 175 mg.L-1), the quantities adsorbed on BC0 are significantly lower than for BC3 and BC7. The increase in SSA with increasing oxygen content could explain these lower adsorbed quantities for BC0, but a difference between the quantities adsorbed on BC3 and BC7 should be observed, which is not the case in our experiments. Li et al. (2019) demonstrated a significant increase (approximately a factor of 10) in tetracycline adsorption with the addition of O_2, rising from 0% to 4% of O_2 present during pyrolysis, linked to the increase in SSA. However, SSA is not the only parameter governing Na retention, other parameters should also be studied, including porosity size and surface functional groups (Nguyen et al. 2022).

In these experiments, a steady increase in the quantity adsorbed as a function of the quantities added was observed without reaching a plateau (Figure 5a). These experiments therefore do not allow us to define the maximum quantity of Na that the biochars can adsorb. The quantity adsorbed for the highest concentration of Na added (1300 mg.L^{-1}) was 6.7 g.kg^{-1} for BC0, 9.0 g.kg^{-1} for BC3 and 8.7 g.kg^{-1} for BC7.

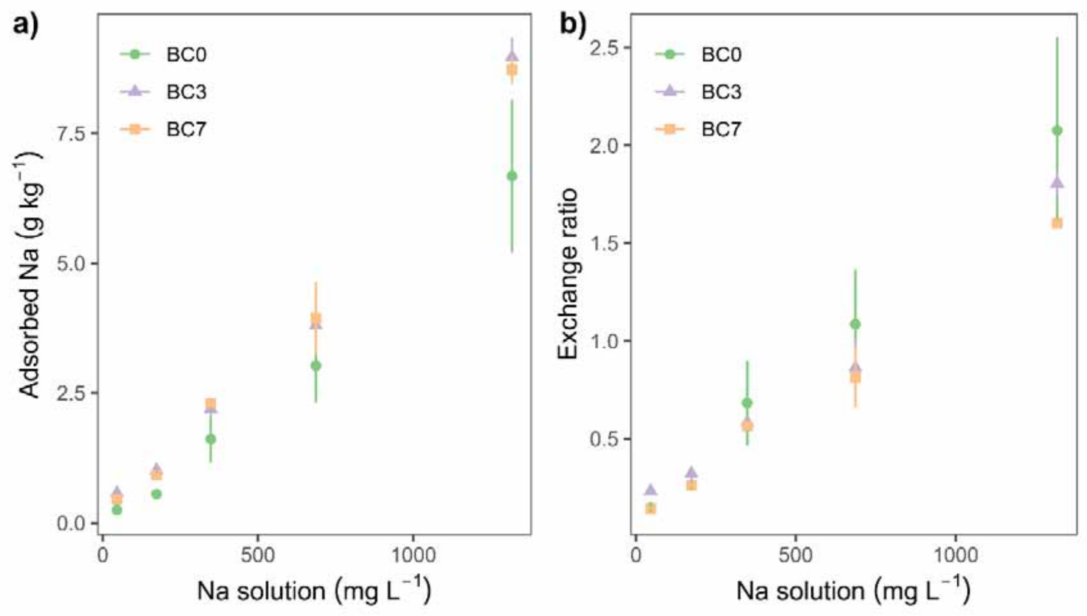

Figure 5 : Concentrations of Na adsorbed on the biochars expressed in g.kg^{-1} of biochar (a) and exchange ratios calculated between adsorbed Na and total released Ca, K and Mg (b) Bars indicate standard deviation of three replicates. (Ponthieu et al., 2025)

These results are comparable with those obtained by Nguyen et al (2022). In their study, for a Na content in solution of 1438 mg.L^{-1}, close to our high point at 1300 mg.L^{-1}, the quantities adsorbed varied between 5 and 25 g.kg^{-1} depending on the biochar considered (different feedstocks were used). Rastamian et al. (2015) worked on chemically activated biochar (rice husk as feedstock), and therefore obtained higher adsorbed quantities (for a Na concentration in solution of 1400 mg.L^{-1}, adsorbed Na was 15 g.kg^{-1}) than those obtained in this work. The quantities of Na adsorbed on biochar are thus of the same order of magnitude in the few studies that have been carried out. They depend on the feedstock used and the conditions under which the biochar is produced.

With increasing Na concentrations in solution, and thus increasing concentrations of adsorbed Na, an increase in Ca, K and Mg concentrations was observed in solution (data not shown). These elements are therefore released during Na adsorption suggesting an exchange between Na and the three cations. Exchange ratios (Figure 5b) were calculated as the ratio between the concentration of Na adsorbed and the sum of the concentrations of Ca, K and Mg released. A ratio of less than 1 means that the quantity of Na adsorbed is less than the quantity of Ca, K and Mg released, so there is an exchange of ions but also a release of Ca, K and Mg linked to the contact of the biochar with water. A ratio greater than 1 means that the amount of Na adsorbed is higher than the amount of Ca, K and Mg released, so Na is adsorbed by ion exchange but also via another process. An increase in the exchange ratio is observed with increasing Na concentrations in solution, with a ratio well above 1 only for the highest Na concentration in solution (1300 $mg.L^{-1}$). The same trend was observed in the study of Nguyen et al. (2022) and the ratios obtained were comparable in both studies. At similar concentration of Na in solution (around 1300-1400 $mg.L^{-1}$), the ratio calculated is between 1.6 and 2.1 for the three biochars of this study and is between 0.2 and 4.2 for the biochars studied in Nguyen et al. (2022). The same processes are therefore involved in the adsorption of Na on these biochars prepared with different feedstocks and under different conditions with, as suggested by Nguyen et al. (2022), a combination of ion exchange and physical adsorption.

2.2.4.3 Na desorption

The desorption experiments were carried out after the adsorption experiments on the samples spiked with 5 concentrations of Na ranging from 45 $mg.L^{-1}$ to 1300 $mg.L^{-1}$ as well as on control experiment.

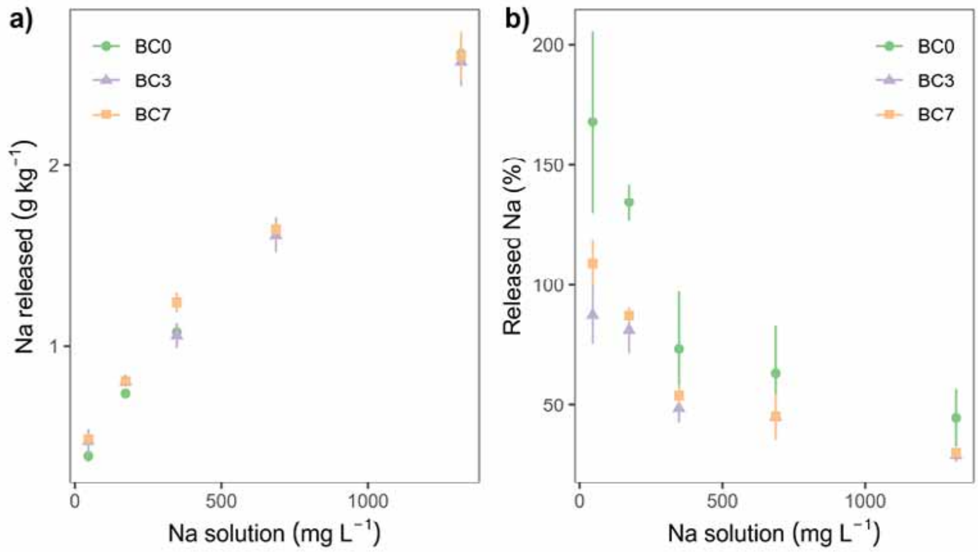

Figure 6 : Concentrations of Na released during desorption experiments as a function of Na concentrations added for adsorption experiments expressed in $g.kg^{-1}$ of biochar (a) and as a percentage of Na concentration adsorbed (b). Bars indicate standard deviation of three replicates. (Ponthieu et al., 2025)

The amount of Na desorbed increase with increasing Na concentrations added and therefore with the increase in Na concentrations adsorbed (Figure 6a). However, the proportion of desorbed Na relative to the quantity adsorbed decreased with increasing added concentrations (Figure 6b). The proportions of Na desorbed decreased from 158 to 39% of the Na adsorbed for BC0 and from an average of 95 to 29% for BC3 and BC7 with the increase of Na concentration in solution. The proportions of Na desorbed are quite high for the three biochars, which seems consistent with the proposed sorption processes i.e. ion exchange and physical adsorption. Based on statistical tests, in just one experiment, the one with Na concentrations in solution of 175mg.L-1, the desorbed Na content is significantly lower and the proportion desorbed significantly higher, for BC0 than for the other two biochars. For all other points, no significant difference was observed. For the lowest concentrations of Na added (45 and 175 mg.L^{-1}), the quantities desorbed for BC0 were greater than the quantities adsorbed. So, despite 5 successive rinses and adsorption experiments, there was still a release of sodium initially present in the biochars.

To our knowledge, no comparable work has been published on the desorption of Na adsorbed on biochar. Gong et al. (2019) worked on biochar produced from rice straw at different temperatures and highlighted very different desorption rate depending on the element considered (NH_4, K, P).

2.2.5 Conclusions

This study revealed a significant release of Ca, K, Mg and Na when the biochars were in contact with water. Five rinses were necessary to stabilise these releases, which nevertheless remained non negligible. The proportions of Na adsorbed on the 3 biochars studied were of the order of 15-20%, i.e. fairly low, whatever the added Na content, and the proportions of Na desorbed in contact with water were high. These results therefore highlight the low retention of Na by the biochars studied. The biochar produced without O_2 (BC0) appeared to retain the least Na, but the differences between the 3 biochars were small, and the impact of the presence of O_2 during pyrolysis on Na adsorption is not very marked. Other studies should be carried out with biochars produced at different temperatures or from different feedstocks to assess their ability to limit soil salinisation.

3 Proposal for a biochar production system

Based on the previous results, partners of the University Mohamed khider of Biskra (UMKB) and University of Batna Hadj Lakhder (UBHL) proposed a design of an artisanal biochar device that can be built and used by farmers. This patent was filed by UMKB, its authors are Aya Masmoudi, Kamel Guimeur, Ali Masmoudi, Abderazzak Debilou and Mouatez Salhi. The supporting documents for this filing are presented in Appendix 1.

The invention is a device for transforming palm and plant waste into biochar. The aim of the invention is to provide a gas pyrolyzer which is i) capable of reaching temperatures high enough for pyrolysis and controllable, ii) inexpensive, and iii) with minimal adverse effects on the environment. This pyrolyzer makes it possible to recover palm waste into biochar as the main product to improve soil quality, into bio-oils, as well as into bio-gas which can be reused as fuel for pyrolysis.

This invention is innovative because it allows:

- the use of city gas instead of electricity, which is less expensive in a country like Algeria,

- the reuse of gases from pyrolysis, and therefore a limitation of air pollution,

- and the control of pyrolysis temperatures, an essential parameter for the properties of biochars.

In the pyrolyzer shown in Figure 7, the container (A) is well insulated with thermal insulation (glass wool) (8), to maintain the heat homogeneity inside. The heat source at the beginning of the process is the city gas (E), after it is replaced by the bio-gas from the thermal decomposition process.

In the center of the container there is a cylinder (B) from bottom to top provided with gas nozzles (D), associated with the main gas pipe (C), supplied by two gas sources: city gas (c2) and bio-gas (c1).

The container (A) also associated with a vacuum pump (1), a pressure gauge and a sensor (3), to empty all the gases contained inside the system, after the closure of the container (11). The two secondary pipes (c1) and (c2) are connected with thermoregulator (15) that controls the temperature during the thermal decomposition of the organic matter. The thermoregulator is linked with the program Arduino that controls all the pyrolysis parameters.

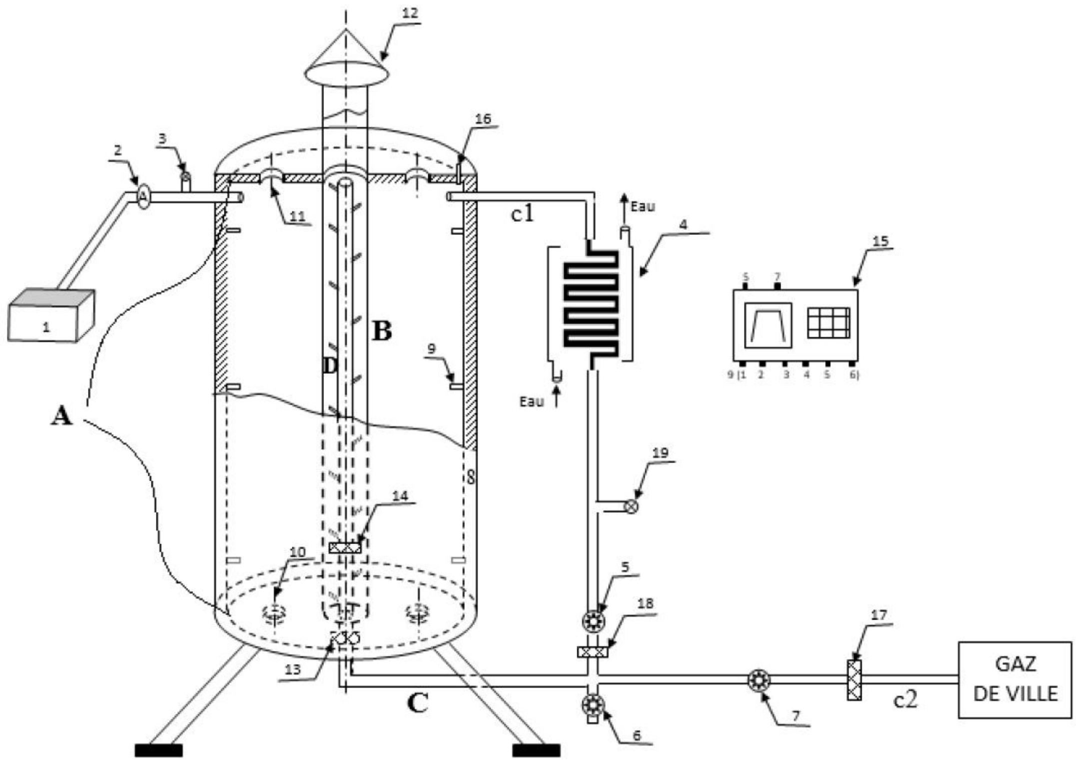

Figure 7 : Device of the pyrolyser

Protocol for biochar production

After filling the container (A) with palm waste via the two openings (11) at the top of the machine, close it tightly.

Then, the thermoregulator is programmed with all the necessary information: temperature, duration and temperature increase per minute.

The vacuum pump is then used, then the Arduino program gives the order to open the city gas solenoid valve (7), and to activate the lighter (13) to light the fire.

The non-return valve (17) is activated to prevent the return of city gas.

The thermocouple (14), associated with the main gas pipe (C) is used to measure the temperature inside the cylinder.

The temperature in the container (A) is also measured using numerous thermal sensors (9) inside the container.
From the moment the biogas is produced, the secondary biogas pipe (c1) receives the gases from the thermal decomposition of the palm tree. The filter (4) is used to remove moisture and fine particles from the biogas.
The pressure gauge (19) checks and measures the pressure of the biogas for use as a heat source.
The biogas solenoid valve (5) will allow the biogas to pass into the main pipe (C). The non-return valve (18) is used to prevent the return of biogas.
The CO_2 resulting from the combustion of the gases exits through the exhaust chimney (12).
The safety valve (16), at the top of the machine, is a protection device against overpressure of the biogas, when the system (11) is opened.
The drain openings (13) are intended to recover the final product (Biochar) at the end of the process.
The solenoid valve (6) is intended to recover the bio-oils or the liquid resulting from the pyrolysis of palm waste.

Conclusion

This invention provides assistance in the field of biochar production. It uses city gas as a heat source at the beginning of the process instead of electricity, which makes it less expensive, and it uses the biogas resulting from the thermal decomposition process as a heat source. The device is equipped with a programmable intelligent electronic device that controls all the devices associated with the machine with known temperatures and times, which confirms the quality of the product production.
A further improvement could be to use part of the date palm residues as fuel to initiate the pyrolysis process. This would avoid using fossil energy and reduce the carbon footprint of biochar production.