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Solutions to Rice Field Degradation in Bona: Evaluating the Effects of Activated Char and Digestate on Low-Yield Soils

Ansoumane Diedhiou[1,2*], Sada Traore[1], Mamadou Seydou Ba[1], Ammar Bensakhria[2]

[1]Laboratoire de Chimie et de Physique des Matériaux, Université Assane Seck de Ziguinchor, Ziguinchor, Sénégal
[2]Centre de recherche de Royallieu, Université de Technologie de Compiègne, Compiègne, France
Email: *ansoumane.diedhiou@univ-zig.sn

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Abstract

Agricultural soil degradation is a major global challenge that threatens food security and sustainable agricultural production through nutrient depletion, erosion, soil salinization, and the loss of organic matter. These processes lead to significant physicochemical changes in rice paddy soils. In the search for sustainable solutions, the present study aimed to evaluate the effectiveness of two types of biofertilizers, namely activated char and digestate. These products were tested on low-yield soils in the village of Bona, Senegal. The experiment consisted of applying 180 g of lemon juice-treated activated char or 180 g of digestate to a 420 g soil samples. A 600 g untreated soil sample served as the control. Physicochemical analyses were conducted on all treatments over a 15-day period to evaluate their effects on soil characteristics. The results showed that the activated char amendment was the most effective treatment, due to its high adsorption capacity, water retention capacity, and ability to regulate fluctuations in chemical components (NPK). In addition, all treatments improved soil pH campered to the control. However, the salinity (620 - 860 mg/kg) observed in the soil amended with digestate may negatively affect rice yields.

Keywords

Low-Yield Soils, Rice Paddy, Soil Amendment, Activated Char, Digestate

1. Introduction

In Senegal, rice is one of the most widely consumed cereal grains, with an estimated per capita consumption of 87.6 kg per year [1]. Although rice cultivation plays a vital role in the country's food security, it faces several challenges, particularly soil salinization in the Lower Casamance region, especially in the municipality of Bona. Soil salinization is a major global environmental issue. According to the FAO, the most recent estimates indicate that it already affects at least 400 million hectares (ha) of land and continues to expand, threatening an additional 5 to 1 ha annually [2]. Furthermore, the deterioration of soil physicochemical properties, including pH, electrical conductivity (EC), salinity, total dissolved solids (TDS), and nutrient content (NPK), represents one of the major constraints to rice production in Lower Casamance [3].

To address this challenge, many studies have focused on soil amendment and fertility improvement. As a result, several management practices have been implemented, including the construction of anti-salinity dikes, small embankments and mulching, which are recognized as traditional strategies for combating the salinization of rice paddies [4] [5]. In addition, various organic soil amendments, such as compost, peanut shells, and fish scales, activated char, and digestate have been investigated for their potential to restore soil fertility [6] [7], as well as biochar, compost, and digestate [8]-[10].

Among these organic amendments, activated char and digestate have attracted increasing attention because of their potential to improve soil quality and fertility. Activated char, in particular, is recognized for its high absorption capacity, which enhances water retention, reduces pollutant mobility, and improves physical and chemical properties of soils.

Againts this background, the present study aims to improve the quality of low-yeild soils in Bona through the application of activated char produced from ditakh shells and digestate derived from cow manure. Specificallly, the study evaluates the effects of these soil amendments on key physicochemical soil properties, including pH, electrical conductivity (EC), temperature, moisture content, salinity, total dissolved solids (TDS), and nutrient content (NPK), in order to assess their potential for restoring soil fertility and enhancing the productivity of rice-growing soils.

2. Materials and Methods

The map was created using a GPS device, which was used to record geolocation points during soil samples collection. It shows the territory of the village of Bona, in the Sédhiou region of Senegal, outlined in red. The map illustrates the local topography, notably featuring the Soungouroungou River, a major watercourse that has been channeled (**Figure 1**).

The legend identifies the various sampling points, including the rice-growing areas.

The map is based on field data collected in November 2025 and uses the UTM Zone 28N coordinate system.

The device shown in **Figure 2** is a 7-in-1 soil tester from GHL Control Pad designed to measure soil moisture, temperature, electrical conductivity (EC), pH, salinity, and NPK levels (nitrogen, phosphorus, potassium). It features an HMI touchscreen and a wired sensor that is inserted directly into the soil. The system is designed for real-time monitoring of soil composition and data logging.

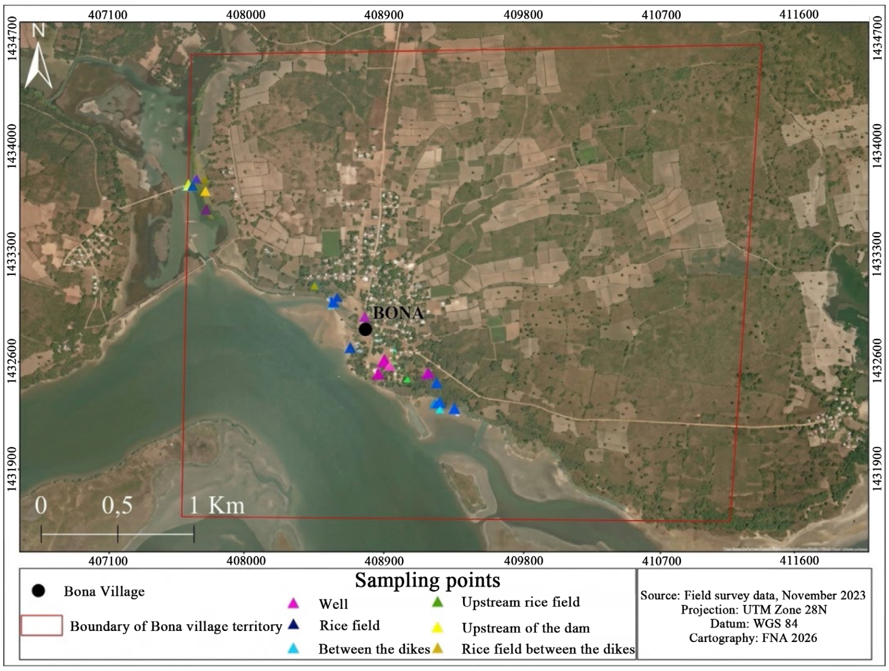


Figure 1. Location of the study areas.

Figure 2. Soil controller and sensor (GHL Control Pad).

To determine the initial physicochemical parameters of the collected soil samples, electrical conductivity (EC), pH, salinity, and the concentrations of nitrogen (N), phosphorus (P), and potassium (K) were measured using the soil tester shown in Figure 2. The results are presented in Table 1. The variations observed in these physicochemical parameters may negatively affect soil quality and crop productivity. Based on these findings, a soil amendment treatment was proposed to restore these properties and maintain them within acceptable ranges.

Table 1. Initial soil values for bona.

Parameters used \ Soils samples	Composite Soil 1	Composite soil 2	Composite soil 3
pH	5.40	5.52	4.92
EC (µS/cm)	389.20	402.43	397.87
Salinity (mg/kg)	199	200	202
N (mg/kg)	19	20	18
P (mg/kg)	25	22	25
K (mg/kg)	50	55	51

Figure 3 illustrates the main steps involved in the preparation of activated carbon. The process can be summarized as follows.

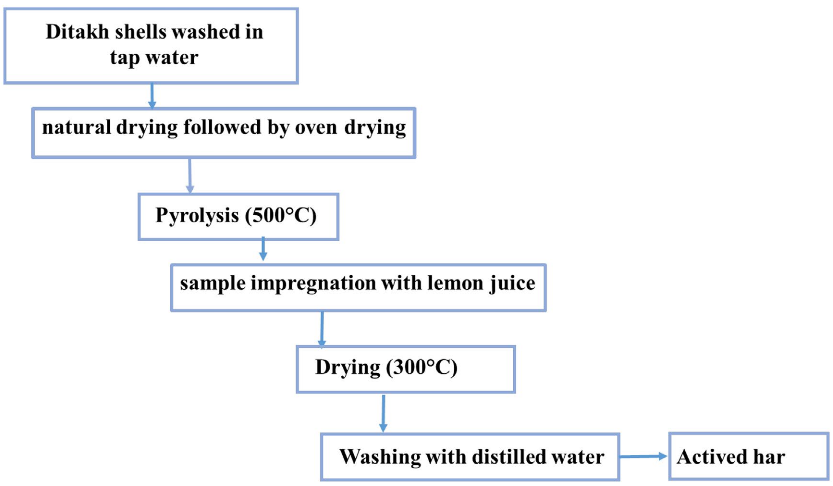


Figure 3. Diagram of the steps involved in producing activated char from ditakh shells (Detarium senegalense).

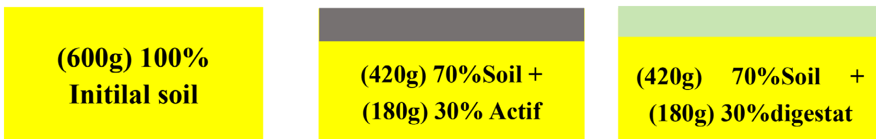
First, the raw material was washed to remove surface impurities. It was then air-dried, followed by oven drying at 105˚C for 48 hours to reduce its moisture content prior to thermal treatment. Pyrolysis was subsequently carried out at 500˚C in the absence of oxygen to produce raw charcoal. The resulting charcoal was impregnated with lemon juice, which acted as a natural acidic activating agent to enhance its porosity. The impregnated charcoal was subsequently heated in a muffle furnace at 300˚C to fix the activating agent and complete the development of the porous structure. Finally, the activated char was washed several times with distilled water to remove acid residues and excess reagents until a neutral pH (pH7) was reached.

However, the digestate used in this study was obtained from a pilot digester at the Laboratory of Chemistry and Materials Physics (LCPM). Following the anaerobic digestion of cow manure, the resulting solid residue (digestate) was collected and used as an organic soil amendment.

Experimental Approach

We worked with three different mixtures of rice-growing soils:

- 100% initial soil (600 g): Pure soil without any additives, used as a control.
- 70% soil + 30% activated char: A mixture consisting of 420 g of soil and 180 g of char activated with lemon juice (or Ditakh shell char).
- 70% Soil + 30% digestate: A mixture consisting of 420 g of soil and 180 g of digestate (a residue from anaerobic digestion), used as a nutrient-rich organic fertilizer.



To ensure that the conditions were identical and to guarantee the reliability of the results, we used the same soil, the same sample mass, the same quantity and type of water (distilled water), and the same measuring equipment. The tests were repeated twice.

3. Results and Discussion

Table 2 provides a summary of the eight key parameters for soil health and crop management (Senegalese Institute for Agricultural Research and Center for Horticultural Development (ISRA and CDH)). Table 2 details the impact of temperature, humidity, and salinity on plant development and germination. Regarding essential nutrients (NPK): It explains the specific role of nitrogen (N) in growth, phosphorus (P) in root development and flowering, and potassium (K) in fruit and tuber development. The table also provides guidance on overall soil fertility (measured by electrical conductivity) and pH (soil acidity) to optimize crop production.

Figure 4 shows the change in moisture content (%) of three types of soil samples (control soil, soil with activated char, and soil with digestate) over time (in minutes). We observe that the curve for the initial soil sample starts at a moisture content of around 92%, then gradually decreases before stabilizing at around 80%.

The moisture curve for the soil with activated char shows a very high residual moisture content (close to 100%) for almost the entire duration. Thus, activated char appears to retain water very effectively, maintaining a moisture content close to saturation. However, the soil-digestate mixture starts with an initial moisture content of about 82%, but this decreases continuously, reaching about 45% toward the end. The digestate appears to promote a faster and greater loss of moisture. The greater water losses observed in the soil mixed with digestate can be explained by increased evaporation, which may be due to the fact that the soil-digestate mixture does not retain water for very long. The initial soil loses moisture but maintains a relatively stable level after an initial drop.

Table 2. ISRA and CDH guidelines and recommendations.

🔣 THE 8 PARAMETERS—WHAT THEY MEAN		
🌡 Temperature	Soil T°	If it's too cold: not good for germination. If it's too hot: burns the roots.
💧 Moisture	Water in the soil	If it's too dry, the plants will die. If it's too wet, the roots will rot.
⚡ EC	Overall Fertility	Measures whether the soil has enough nutrients. Low = poor soil (1000 - 2000 µS/cm). High = too much fertilizer or salty soil.
▯ pH	Soil acidity	Between 6 and 7 = suitable for most crops. Too acidic = apply lime. Too alkaline = apply sulfur.
🌿 Nitrogen (N)	Growth	Nitrogen helps plants grow. Bottom = yellow leaves. Top = lodging and diseases.
🌿 Phosphorus (P)	Roots & Flowering	Phosphorus promotes root and flower development. It is not very mobile in the soil.
🌿 Potassium (K)	Fruits & Tubers	Potassium produces high-quality fruit. It is essential for onions, tomatoes, and peanuts.
▯ Salinity	Salt in the Soil	Soil that is too salty (a value well above 500 mg/kg) prevents plants from absorbing water. Coastal and irrigated areas: monitor closely.

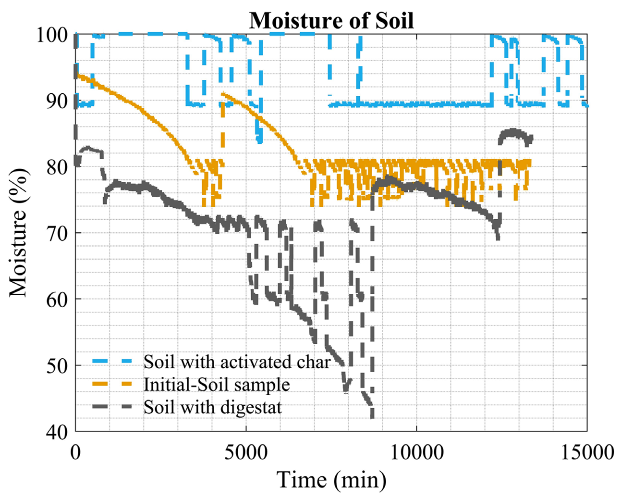


Figure 4. Changes in moisture content (%) vs time for three types of samples.

Figure 5 illustrates the changes in the pH of Bona soil over a period of 15,000 minutes (approximately 10 days) for three different samples. We worked with the control soil sample hydrolyzed with distilled water; then, another control soil sample of the same mass was mixed with digestate, and the third with activated char. As shown in this figure, the control soil sample exhibits the most acidic pH, with a baseline pH of around 6.3. A sharp drop to a pH of 5.1 is observed around 5500 minutes, followed by a gradual rise that stabilizes around the initial pH of 6.3. The pH trend for the soil amended with digestate shows the highest pH, generally fluctuating between 7.0 and 7.7. The addition of digestate appears to make the soil more alkaline (basic) compared to the other samples. However, the soil-activated char mixture exhibits a relatively stable pH ranging from 6.8 to 7.0. Activated char appears to act as a buffer, stabilizing the pH near neutrality.

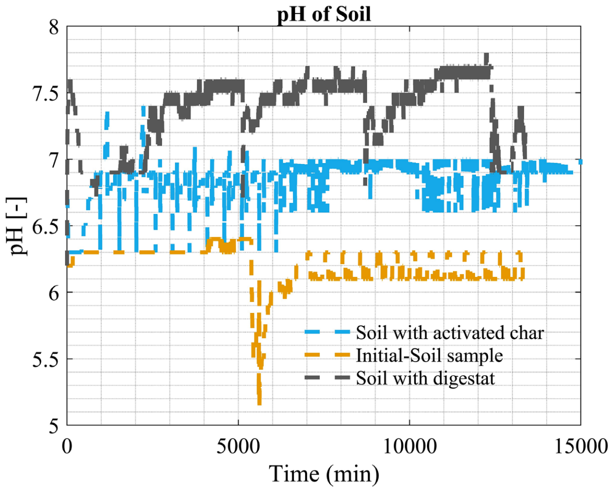


Figure 5. Changes in the pH of Bona soil vs time for three samples.

Figure 6 compares the temperature changes in three soil samples over a period of 15,000 minutes. The soil with activated char exhibits moderate fluctuations, remaining generally between 26˚C and 32.5˚C. However, the initial soil sample shows the greatest drop in temperature, reaching a minimum of approximately 24.5˚C around 12,500 minutes. Finally, the soil with digestate exhibits the most frequent and rapid variations, with peaks reaching 33˚C. In summary, the addition of activated char appears to stabilize soil temperature more effectively compared to digestate or untreated soil, which undergo more extreme variations.

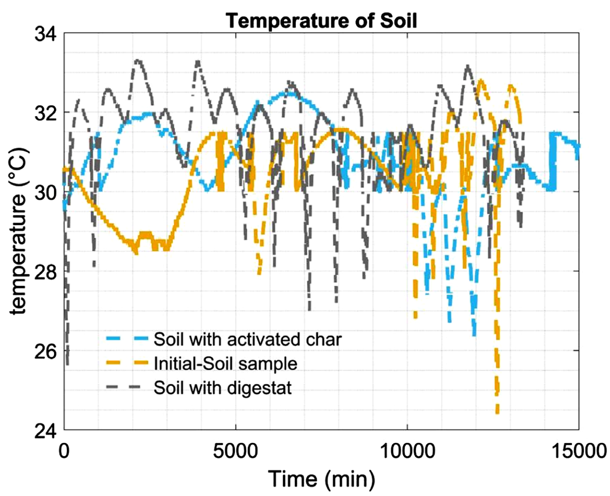


Figure 6. Temperature changes in three soil samples vs time.

Temperature governs the soil's physicochemical and biological processes and also influences gas exchange between the atmosphere and the soil. Soil temperature affects the rate of organic matter decomposition as well as the mineralization of various organic materials. It also affects soil moisture content, soil conductivity, and the availability of water to plants.

Figure 7 illustrates the change in electrical conductivity (EC) of three types of soil samples over a period of 15,000 minutes.

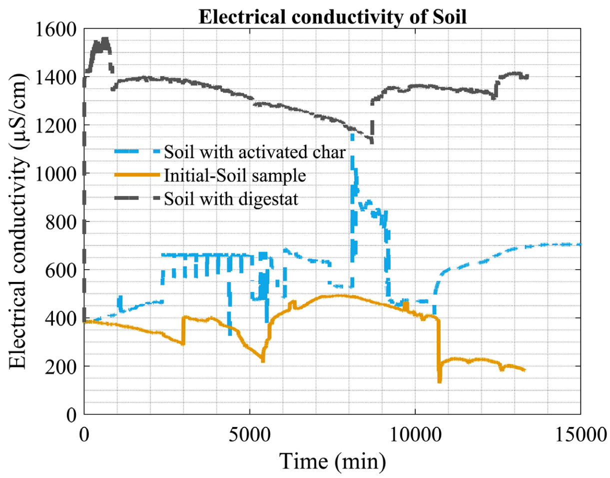


Figure 7. Changes in the electrical conductivity of three soil samples vs time.

The soil mixed with 30% digestate exhibits the highest conductivity, generally ranging between 1200 and 1500 μS/cm. This is due to the high mineral salt and nutrient content of the digestate.

The soil mixed with activated char, on the other hand, exhibits intermediate values, mostly ranging between 400 and 800 μS/cm, with notable irregular peaks around 8000 minutes. However, the initial soil sample has the lowest conductivity, remaining generally below 500 μS/cm, with a downward trend toward the end of the experiment.

The addition of digestate drastically increases the soil's electrical conductivity compared to the control soil. The curves are not smooth, suggesting dynamic chemical reactions or environmental changes that influence ion mobility over time.

The curve for the soil-digestate mixture shows the highest phosphorus concentration, fluctuating mostly between 80 and 110 mg/kg (Figure 8). The variation in the curve for soil mixed with activated charcoal falls at an intermediate level, starting at around 45 mg/kg and ending at around 50 mg/kg, following significant fluctuations. Thus, the variation curve for the initial soil sample shows the lowest phosphorus concentration, remaining generally below 35 mg/kg.

The addition of digestate significantly increases the phosphorus concentration in the soil compared to the initial soil. Activated carbon also increases this concentration, but to a more moderate extent.

Figure 9 shows the change in soil nitrogen concentration over time for three different samples. We observe the lowest nitrogen level in the control soil curve.

The concentration starts at around 20 mg/kg, drops slightly until it reaches a minimum of approximately 10 mg/kg at around 5300 min. It then rises, plateauing at around 24 mg/kg between 7000 and 9000 min, before falling back below 10 mg/kg at the end of the experiment. The curve for the soil-activated char mixture, meanwhile, shows intermediate values. From the start, the nitrogen concentration rises rapidly, stabilizing between 45 and 50 mg/kg. A gradual decline is then observed, reaching 32 mg/kg at 7500 min.

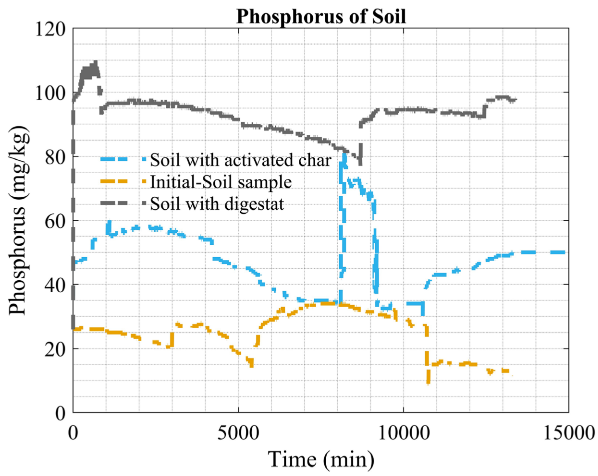


Figure 8. Changes in soil phosphorus levels vs time for three samples.

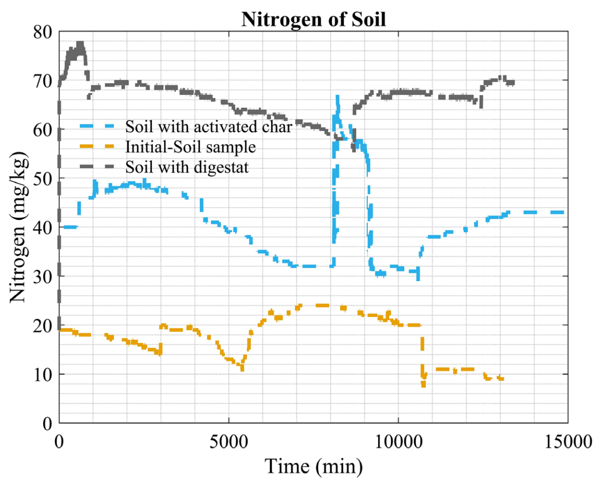


Figure 9. Changes in soil nitrogen content vs time for three samples.

A sudden and very pronounced peak occurs around 8000 min, reaching nearly 67 mg/kg, followed by a sharp drop to 30 mg/kg. The level finally rises slightly toward the end of the experiment, stabilizing around 43 mg/kg. The use of the soil-digestate mixture is the treatment that most consistently enriches the soil with nitrogen. A massive increase occurs within the first few minutes, reaching a maximum peak of approximately 77 mg/kg. The level decreases slightly but remains very high, fluctuating between 60 and 70 mg/kg throughout the measurement period.

The addition of digestate or activated carbon significantly increases the nitrogen concentration in the soil compared to the initial soil. Digestate (gray curve) provides the highest and most stable nitrogen supply over time, remaining consistently above (60 mg/kg).

Figure 10 shows the change in potassium concentration (mg/kg) in the soil over time (in minutes) for three different samples. The soil-digestate mixture consistently has the highest potassium content, generally ranging between 180 mg/kg and 250 mg/kg. However, the curve for the soil with activated char shows a potassium concentration at an intermediate level, generally varying between 70 mg/kg and 120 mg/kg, with a significant temporary peak around 8000 min reaching approximately 180 mg/kg. The initial soil sample had the lowest potassium content of the entire experiment, remaining mostly below 80 mg/kg.

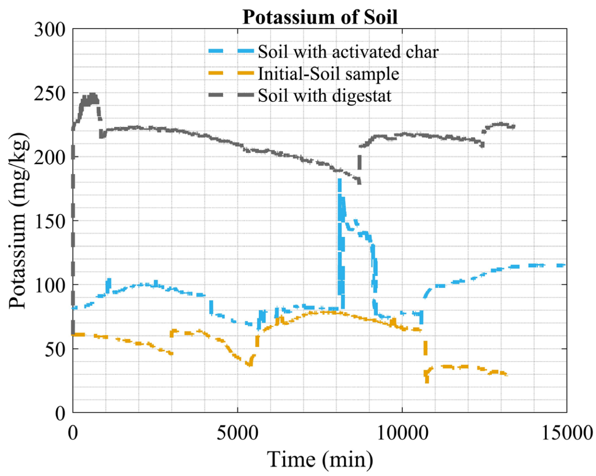


Figure 10. Changes in soil potassium levels vs time for three samples.

The salinity (620 - 860 mg/kg) observed in soil amended with digestate could have negative repercussions on the yields of crops that could be grown on these rice-growing soils (Figure 11); this same problem was highlighted by researchers

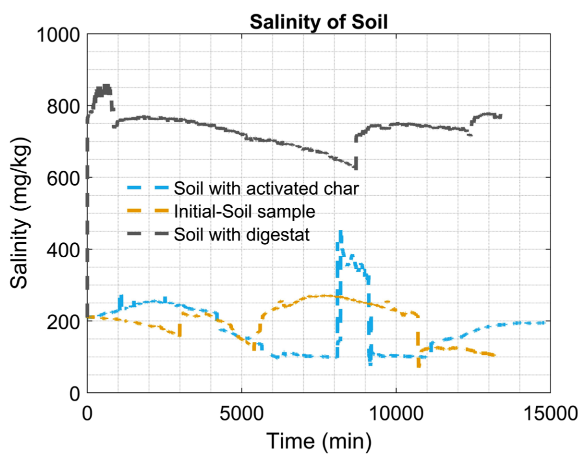


Figure 11. Changes in soil salinity vs time for three samples.

[11] and [12]. And according to the values recommended (150 - 500 mg/kg) by the Center for Horticultural Development and the Senegalese Institute for Agricultural Research (ISRA/CDH), the values (620 - 860 mg/kg) are well above normal. However, the soil-activated char mixture curve remains mostly below 300 mg/kg, close to that of the initial soil.

A very sharp and temporary spike in salinity, reaching over 400 mg/kg, is observed around 8000 minutes into the mixing of the soil with the activated char.

4. Conclusions

Activated char and digestate improve soil through different yet complementary mechanisms, influencing its physical, chemical, and biological properties to restore the fertility of degraded land.

Here's how each of these soil amendments influences soil quality, according to various sources:

- Active char, produced by pyrolysis from ditakh shells and activated with lemon juice, is primarily distinguished by its role as a thermal regulator, pH stabilizer, and water and moisture retainer. Thanks to its porosity, it retains pollutants and nutrients, resulting in a moderate but steady increase in nitrogen, phosphorus, and potassium (NPK) levels compared to untreated soil. It also maintains salinity at low and acceptable levels (generally below 300 mg/kg), thereby protecting crops in high-risk areas such as Bona.
- Digestate, produced through the anaerobic digestion of cow manure, acts as a powerful organic fertilizer rich in nutrients (NPK). It is the treatment that provides the highest concentration of nutrients. It dramatically increases the levels of nitrogen (maintained above 60 mg/kg), phosphorus, and potassium. The addition of digestate makes the soil more alkaline (basic), with a pH ranging between 7.0 and 7.7. It significantly increases the soil's electrical conductivity (between 1200 and 1500 μS/cm), indicating a high content of mineral salts and available nutrients. Although these amendments are beneficial, sources note certain side effects associated with digestate: digestate may lead to high salinity (620 - 860 mg/kg), exceeding ISRA/CDH recommendations (150 - 500 mg/kg), which can adversely affect rice yields. It promotes faster moisture loss due to increased evaporation compared to activated char.

In summary, while activated carbon excels at improving soil structure and stabilizing the soil, digestate is more effective for providing rapid and intensive nutrient supply.

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Author Contributions

Conceptualization, Ansoumane DIEDHIOU. and Sada TRAORE; methodology, Ansoumane DIEDHIOU; formal analysis, Ansoumane DIEDHIOU, and Mamadou Seydou BA; investigation, Ansoumane DIEDHIOU. and Sada TRAORE; resources, Ansoumane DIEDHIOU; writing—original draft preparation, Ansoumane DIEDHIOU; writing—review and editing, Ansoumane DIEDHIOU; visualization, Ansoumane DIEDHIOU. Sada TRAORE an Mamadou Seydou BA; supervision, Ammar BENSAKHRIA.; project administration, Ansoumane DIEDHIOU and Ammar BENSAKHRIA; All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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