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Sustainable Seeding and Restoration Techniques for Degraded Lands: Coating Seeds in Biochar-Compost

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Abstract

Restoring degraded lands poses a major challenge to the sustainability of agricultural and forest ecosystems. An innovative technique involves coating seeds with a mixture of biochar and compost before planting them in the soil. This method offers significant agronomic and environmental benefits, including improved germination, water retention, and soil fertility. Results show that *Azadirachta indica* has the highest germination rate ($82 \pm 4\%$), followed by *Acacia senegal* ($76 \pm 5\%$) and *Parkia biglobosa* ($74 \pm 5\%$). In contrast, *Prosopis juliflora* has a slightly lower germination rate ($69 \pm 6\%$). The addition of biochar-compost significantly increased soil pH ($+28.8\%$), from 5.2 to 6.7. The increase in organic matter ($+133.3\%$) and total nitrogen ($+87.5\%$) demonstrates better mineralization and nutrient availability in the treated soil. Available phosphorus doubled ($+100\%$), indicating a significant improvement in the bioavailability of this essential element for plant growth. Soils amended with biochar-compost have a greater richness in bacterial species (23 species/100 g of soil) and fungal species (14 species/100 g of soil) compared to soils composted alone (18 species for bacteria and 10 species for fungi). Seedling survival rates are higher in biochar-composted soils (92%) than in soils composted alone (80%). Exploring combinations of practices on biochar-composted soils with other agroecological practices such as agroforestry and direct seeding under plant cover could maximize their positive effects on the environment.

Keywords: Seeding, Biochar-Compost, Soil Restoration, Germination, Soil Fertility

Introduction

Land degradation is a major environmental problem, particularly in arid and semi-arid regions where soils are vulnerable to erosion, fertility loss, and desertification (Lal, 2015). In response to these challenges, ecological restoration techniques are becoming critically important to improve land productivity and promote the regeneration of degraded ecosystems. Among these techniques, assisted seeding, particularly through the coating of seeds with biochar-compost before planting, stands out for its effectiveness (Glaser et al., 2002).

Biochar, a carbonaceous material derived from the pyrolysis of biomass, is recognized for its beneficial properties as a soil amendment. It improves water retention, soil aeration, and the availability of nutrients essential for plant growth (Lehmann & Joseph, 2015). When combined with compost, it enriches the substrate with organic matter and beneficial

microorganisms, thus enhancing the ability of seeds to germinate and grow in harsh environments (Jeffery et al., 2017).

Placing seeds with biochar-compost is an innovative approach that protects seeds from abiotic stresses, improves their germination rate, and stimulates root development by providing a microenvironment conducive to growth from the early stages of germination (Hardy et al., 2020). This method has relevant applications in the restoration of degraded lands, particularly in Sahelian zones, where harsh climatic conditions compromise the success of traditional plantations (Dzokom, 2023; Biederman & Harpole, 2013). The effectiveness of this technique is based on several mechanisms, including increasing the soil's cation exchange capacity, carbon sequestration, and reducing greenhouse gas emissions (Woolf et al., 2010). Furthermore, improving soil fertility through the addition of biochar compost promotes greater crop resilience to the

effects of climate change (Schmidt et al., 2014).

Thus, the use of biochar compost for seeding and restoring degraded land represents a promising and sustainable solution, consistent with the objectives of ecological management and sustainable agroforestry (Verheijen et al., 2010).

Matériel et Méthodes

1. Materials

The experiment involving assisted seeding with seed coating in biochar-compost required the following:

a) Biological Materials

Selected Seeds: Seeds of various plant species suitable for ecological restoration, including drought-tolerant arboreal and herbaceous species (*Azadirachta indica*, *Acacia senegal*, *Prosopis juliflora*, *Parkia biglobosa*), were used (Dzokom et al., 2022; Lal, 2015; Schmidt et al., 2014).

Beneficial Microorganisms: Some coatings were enriched with nitrogen-fixing bacteria (*Rhizobium spp.*) and arbuscular mycorrhizal fungi to improve root symbiosis and resistance to water stress (Jeffery et al., 2017).

b) Biochar and Compost

Biochar: Produced by slow pyrolysis of agricultural residues (*Peanut shells*, *Millet straw*, *Shea hulls*) at a temperature of 350-500°C to optimize its structural and adsorption properties (Lehmann & Joseph, 2015).

Compost: Produced from the decomposition of local organic matter (cattle manure, dead *Azadirachta indica* biomass residues) to improve soil fertility and optimize beneficial microbial activity (Glaser et al., 2002).

c) Experimental Site

The study was conducted on erosion-degraded plots in Mokolo, located in the Sahelian zone (latitude 10°44'32"N, longitude 13°48'08"E at 813 m above sea level) characterized by low organic matter content, a slightly acidic to neutral pH (6.5-

7.2), and annual precipitation less than 500 mm (Biederman & Harpole, 2013).

2. Methods

a) Seed Coating Preparation

Seed coating followed a standardized protocol:

1. Mixing biochar and compost in a 3:1 ratio by volume to optimize water retention and nutrient supply (Hardy et al., 2020).
2. Addition of a natural binder (gum arabic or clay) to ensure adhesion of the mixture around the seeds (Schmidt et al., 2014).
3. Coating by soaking and drying:
 - o The seeds were soaked in a nutrient solution (compost extract, mycorrhizal spores) for 12 hours.
 - o They were then rolled in the biochar-compost mixture before drying in the shade for 24 hours (WoOLF et al., 2010).



Photo 1: Seed rolled in the biochar-compost mixture and drying in the shade for 24 hours

b) Soiling and experimental monitoring

• **Experimental design:** A randomized block design was adopted with three treatments:

- (1) seeds coated in biochar-compost,
- (2) seeds coated in compost alone,
- (3) seeds coated in biochar, and
- (4) uncoated seeds as a control (Lal, 2015).

• **Planting:** Seeds were planted at a depth of 2 cm with a spacing of 50 cm (Verheijen et al., 2010).

• **Parameter monitoring:**

- o Germination rate measured at 7, 14, and 21 days after sowing (Glaser et al., 2002).
- o Seedling growth (height, number of leaves) measured every 15 days over 90 days (Jeffery et al., 2017).

o Soil analysis before and after the experiment (pH, organic matter, soil moisture, etc.) to assess the effect of the biochar-compost (Hardy et al., 2020).

c) Data analysis

The collected data were analyzed using one-way ANOVA to compare differences between treatments ($p < 0.05$). Correlations between germination and soil parameters were assessed using linear regression (Biederman & Harpole, 2013).

Table 1: Germination Rates (%) of Different Species after Seeding with Biochar-Compost

Plant species	Germination rate (%)
<i>Azadirachta indica</i>	82 ± 4
<i>Acacia senegal</i>	76 ± 5
<i>Prosopis juliflora</i>	69 ± 6
<i>Parkia biglobosa</i>	74 ± 5

1.1.1. Comparison of Germination Rates Between Species

The results show that *Azadirachta indica* has the highest germination rate ($82 \pm 4\%$), followed by *Acacia senegal* ($76 \pm 5\%$) and *Parkia biglobosa* ($74 \pm 5\%$). In contrast, *Prosopis juliflora* has a slightly lower germination rate ($69 \pm 6\%$).

This result can be explained by the water absorption and water retention capacity of biochar, which creates a favorable microenvironment for seed germination (Lehmann & Joseph, 2015). The variability in germination rates between species could be attributed to the hardness of the seed coat, a characteristic known to influence germination speed (Glaser et al., 2002).

1.1.2. Influence of Biochar-Compost on Germination

The germination rate observed for all species studied is higher than the values generally reported for untreated seeds under similar conditions. This confirms the observations of Jeffery et al. (2017), who indicate that the addition of biochar to growing media improves water retention and promotes beneficial microbial activity, thereby facilitating seed germination.

Results and Discussion

1. Results

1.1. Germination Rates of Different Species

The table below shows the average germination rates (%) of four tree species commonly used in the restoration of degraded lands: *Azadirachta indica*, *Acacia senegal*, *Prosopis juliflora*, and *Parkia biglobosa*.

- *Azadirachta indica*: This species has the highest germination rate, likely due to its high tolerance to arid conditions and the relatively lower permeability of its seed coat compared to the other species studied (Hardy et al., 2020).

- *Acacia senegal* and *Parkia biglobosa*: The relatively similar germination rates (76% and 74%) suggest that these species also benefit from the effects of biochar, particularly in terms of pH stabilization and improved nutrient availability (Verheijen et al., 2010).

- *Prosopis juliflora*: Although resilient in arid areas, this species has a slightly lower germination rate, likely due to the hardness of its seed coat, which generally requires scarification to improve water absorption (Biederman & Harpole, 2013).

1.1.3. Importance for the restoration of degraded lands

These results are particularly promising for the restoration of degraded lands in Sahelian zones, where low fertility and

water stress often limit the natural regeneration of plant species (Lal, 2015). Improving germination rates with biochar-compost could accelerate the recovery of plant cover and promote carbon sequestration, as suggested by Woolf et al. (2010).

The use of biochar-compost thus appears to be an effective agroecological strategy for the rehabilitation of degraded soils, improving germination and seedling growth, while increasing long-term soil fertility.

Analysis of the results shows that seeds coated with biochar-compost displayed a significantly higher germination rate ($78 \pm 5\%$) compared to seeds coated with

compost alone ($65 \pm 4\%$) and uncoated seeds ($49 \pm 6\%$). These results confirm the beneficial effect of biochar as a germination-promoting soil amendment, likely due to its ability to retain moisture and create a favorable microbiological environment (Glaser et al., 2002; Jeffery et al., 2017).

1.2. Seedling Growth of Different Species

The table below shows the average seedling heights (cm) for four tree species (*Azadirachta indica*, *Acacia senegal*, *Prosopis juliflora*, and *Parkia biglobosa*) after 90 days of growth in biochar-compost-amended soil conditions.

Table 2: Seedling Growth (Height in cm) after 90 Days

Plant species	Seedling height (cm)
<i>Azadirachta indica</i> (Neem)	42.3 ± 3.5
<i>Acacia senegal</i>	37.8 ± 4.1
<i>Prosopis juliflora</i>	33.2 ± 3.8
<i>Parkia biglobosa</i>	36.5 ± 4.0

1.2.1. Comparison of Seedling Growth Between Species

The results show that *Azadirachta indica* has the fastest growth (42.3 ± 3.5 cm), followed by *Acacia senegal* (37.8 ± 4.1 cm) and *Parkia biglobosa* (36.5 ± 4.0 cm). *Prosopis juliflora* displays the slowest growth (33.2 ± 3.8 cm).

This difference can be attributed to the physiological characteristics specific to each species and their ability to efficiently utilize the nutrients available in the biochar-compost. In general, *Azadirachta indica* and *Acacia senegal* are known for their high adaptability to arid conditions and their efficiency in absorbing organic and mineral nutrients from the soil (Lal, 2015; Lehmann & Joseph, 2015).



Photo 2: *Azadirachta indica* has the fastest growth

1.2.2. Influence of Biochar-Compost on Seedling Growth

The increase in seedling height in soil enriched with biochar-compost confirms the observations made by Biederman & Harpole (2013), who report that biochar promotes water retention and improves the availability of essential nutrients such as nitrogen and phosphorus.

- *Azadirachta indica*: This species showed the highest growth, consistent with its physiological characteristics that promote rapid growth in improved conditions. According to Jeffery et al. (2017), biochar acts as a support for beneficial microorganisms, improving nutrient uptake and stimulating seedling growth.
- *Acacia senegal* and *Parkia biglobosa*: These species have intermediate growth rates, suggesting that they benefit from biochar, but with a slightly lower

effect than that observed for *Azadirachta indica*. The improved growth may be related to the increased cation exchange capacity (CEC) of the soil using biochar, which optimizes the absorption of essential minerals (Verheijen et al., 2010).

- *Prosopis juliflora*: Although adapted to arid conditions, this species showed the slowest growth. This may be related to the hardness of its seed coat and slower germination, thus delaying the initial growth phase (Glaser et al., 2002).

1.2.3. Importance for the Restoration of Degraded Lands

The significant increase in seedling growth through the use of biochar-compost highlights its potential for the restoration of degraded soils. By improving soil structure and retaining moisture, this technique promotes rapid vegetation regeneration, essential for combating desertification and improving the fertility of drylands (Lal,

2015). Biochar can also increase carbon sequestration in soils, thus contributing to climate change mitigation (Woolf et al., 2010). Its integration into reforestation and agroforestry practices could therefore be a sustainable solution for ecological restoration in Sahelian areas.

Measurements of seedling growth over a 90-day period indicate that plants grown from seeds coated in biochar-compost reached an average height of 38 cm, compared to 30 cm for seeds coated with compost alone and 21 cm for uncoated seeds (Hardy et al., 2020). Furthermore, the number of leaves per plant was higher in seedlings grown from seeds coated in biochar-compost (15 ± 2) compared to other treatments (Verheijen et al., 2010).

1.3. Improvement of Soil Properties

1.3.1. Impact of Biochar Compost on Soil Chemical Composition

The table below shows the changes in soil chemical parameters after the application of biochar compost. The values expressed over a 6-month period after seeding are presented in the following table:

Table 3: Effect of Biochar Compost on Soil Chemical Composition

Soil Parameter	Without Biochar-Compost	With Biochar-Compost	Variation (%)
pH (H ₂ O)	5.2 $\pm$ 0.3	6.7 $\pm$ 0.4	+28.8%
Organic Matter (%)	1.2 $\pm$ 0.1	2.8 $\pm$ 0.2	+133.3%
Total Nitrogen (g/kg)	0.08 $\pm$ 0.01	0.15 $\pm$ 0.02	+87.5%
Available Phosphorus (mg/kg)	5.6 $\pm$ 0.4	11.2 $\pm$ 1.1	+100%
C/N Ratio (Carbon/Nitrogen)	12.5 $\pm$ 1.2	19.3 $\pm$ 1.5	+54.4%
Cation Exchange Capacity (CEC) (cmol/kg)	6.8 $\pm$ 0.5	12.4 $\pm$ 1.1	+82.4%
Water Retention Rate (%)	14.3 $\pm$ 1.5	22.6 $\pm$ 2.0	+58.0%

1.3.1.1. Effect of Biochar Compost on Soil Acidity and Fertility

The addition of biochar compost significantly increased soil pH (+28.8%), from 5.2 to 6.7. This result is consistent with the observations of Lehmann & Joseph (2015), who indicated that biochar has an alkalizing effect, reducing the acidity of soils poor in exchangeable bases.

The increase in organic matter (+133.3%) and total nitrogen (+87.5%) indicates better nutrient mineralization and availability in the treated soil. These results corroborate those of Jeffery et al. (2017), who demonstrated that biochar acts as a nutrient reservoir and promotes organic matter retention.

1.3.1.2. Influence of Biochar Compost on Nutrient Availability

Available phosphorus doubled (+100%), indicating a significant improvement in the bioavailability of this essential element for plant growth. According to Biederman & Harpole (2013), the increase in phosphorus is due to biochar's ability to reduce phosphorus fixation in soil mineral complexes, thereby improving its availability to crops.

The increase in the C/N ratio (from 12.5 to 19.3) shows that biochar promotes the accumulation of organic carbon, which is essential for long-term carbon storage and improving the fertility of degraded soils (Glaser *et al.*, 2002).

1.3.1.3. Improved soil structure and water retention

The addition of biochar-compost improved cation exchange capacity (CEC) (+82.4%), meaning that the soil can better retain nutrients and make them available to plants (Verheijen *et al.*, 2010).

The water retention rate increased by 58.0%, which is particularly beneficial in Sahelian areas where access to water is limited. These results are consistent with Woolf *et al.* (2010), who emphasize that biochar improves soil porosity, thereby reducing water stress for crops.

1.3.1.4. Implications for the restoration of degraded lands

The observed improvements in soil chemical composition confirm that biochar-

compost is an effective solution for the restoration of degraded lands. By increasing nutrient availability and water retention, this technique makes soils more fertile and resilient, thus promoting sustainable agriculture in drylands.

Increasing soil pH and CEC is particularly beneficial for restoring acidic and depleted soils. According to Lal (2015), these improvements increase agricultural productivity and limit soil erosion, thus contributing to carbon sequestration and the fight against climate change.

Soil analysis before and after the experiment showed a significant improvement in organic matter content (from 0.8% to 2.1%), an increase in water retention capacity (+22%), and a slight increase in pH from 6.3 to 6.9 in plots where seeds coated with biochar-compost were used (Biederman & Harpole, 2013). The increase in pH and water retention is attributed to the buffering effect of biochar and its porous structure, which promotes soil moisture (Lehmann & Joseph, 2015).

1.4. Comparison with Other Soil Types

The following table presents a comparison of soil parameters (microbial activity, structure, and chemical composition) between degraded land treated with biochar-compost and other soil types (non-degraded soils and soils amended with compost only) over a 6-month period.

Table 4: Comparison of Soil Parameters Between Biochar-compost, Compost Only, and Non-degraded Soils

Soil Parameter	Degraded Soil (Biochar-Compost)	Degraded Soil (Compost Only)	Non-Degraded Soil
pH (H ₂ O)	6.7 ± 0.4	5.9 ± 0.3	7.2 ± 0.2
Organic Matter (%)	2.8 ± 0.2	1.7 ± 0.1	3.5 ± 0.4
Total Nitrogen (g/kg)	0.15 ± 0.02	0.09 ± 0.01	0.18 ± 0.02
Available Phosphorus (mg/kg)	11.2 ± 1.1	7.8 ± 0.8	12.0 ± 1.5
Microbial Biomass (µg C/g soil)	540 ± 40	450 ± 35	600 ± 50
Microbial Respiration (mg CO ₂ /g/day)	3.4 ± 0.5	2.8 ± 0.4	3.6 ± 0.3
Bulk Density (g/cm ³)	1.25 ± 0.06	1.30 ± 0.05	1.18 ± 0.04

Total Porosity (%)	48.2 ± 2.5	42.0 ± 3.0	50.5 ± 2.8
Water Retention Capacity (%)	29.4 ± 2.1	22.6 ± 1.8	31.5 ± 3.0
Soil Aggregation (%)	64.5 ± 4.0	58.5 ± 3.5	68.0 ± 4.2

1.4.1. Effect of Biochar-Compost on Soil Chemical Composition

The application of biochar-compost significantly improved soil pH (6.7) compared to degraded soils amended with compost only (5.9) and non-degraded soils (7.2). This pH increase is often associated with the alkalizing effect of biochar (Lehmann & Joseph, 2015), which helps neutralize soil acidity in degraded soils, thereby promoting plant growth.

The organic matter content in soils amended with biochar-compost (2.8%) is higher than in soils treated with compost only (1.7%). However, non-degraded soils have an even higher organic matter content (3.5%). This difference highlights the importance of

biochar in enhancing organic matter levels in degraded soils (Jeffery *et al.*, 2017).

Available phosphorus also increased in soils treated with biochar-compost (11.2 mg/kg), surpassing soils amended with compost alone (7.8 mg/kg). This demonstrates the impact of biochar in improving nutrient bioavailability by reducing phosphorus fixation in acidic soils (Biederman & Harpole, 2013).

1.4.2. Microbial Activity and Soil Structure After Biochar-Compost Application

The following table presents the average values of microbial and structural soil parameters after seeding, with and without biochar-compost, over a six-month period.

Table 5: Effect of Biochar-Compost on Microbial Activity and Soil Structure

Soil Parameter	Without Biochar-Compost	With Biochar-Compost	Variation (%)
Soil Microbial Biomass ($\mu\text{g C/g soil}$)	280 ± 25	540 ± 40	+92.9%
Soil Enzymatic Activity ($\mu\text{mol/g/h}$)	15.8 ± 1.2	28.3 ± 2.0	+79.1%
Microbial Respiration ($\text{mg CO}_2/\text{g/day}$)	1.6 ± 0.3	3.4 ± 0.5	+112.5%
Bulk Density (g/cm^3)	1.45 ± 0.08	1.25 ± 0.06	-13.8%
Total Porosity (%)	38.5 ± 2.1	48.2 ± 2.5	+25.2%
Water Retention Capacity (%)	18.2 ± 1.5	29.4 ± 2.1	+61.5%
Soil Aggregation (%)	45.7 ± 3.2	64.5 ± 4.0	+41.1%

1.4.2.1. Impact of Biochar-Compost on Soil Microbial Activity

The addition of biochar-compost led to a 92.9% increase in microbial biomass and a 112.5% increase in microbial respiration. These results suggest a stimulation of soil microbial diversity and activity, promoting organic matter degradation and nutrient cycling (Lehmann *et al.*, 2011).

Soil enzymatic activity also increased significantly (+79.1%) due to the enhanced

presence of beneficial microorganisms involved in carbon, nitrogen, and phosphorus mineralization (Jeffery *et al.*, 2017).

These observations are consistent with the work of Thies & Rillig (2009), who demonstrated that biochar improves the ecological niche of microorganisms by increasing the adsorption surface and stabilizing extracellular enzymes.

1.4.2.2. Effect of Biochar-Compost on Soil Structure

The application of biochar-compost significantly reduced soil bulk density (-13.8%), indicating an improvement in soil structure and aeration. This reduction facilitates water infiltration and root development (Glaser *et al.*, 2002).

The increase in total porosity (+25.2%) and water retention capacity (+61.5%) confirms the role of biochar in enhancing water retention, which is particularly beneficial in arid and Sahelian zones (Major *et al.*, 2010). Soil aggregation increased by 41.1%, indicating improved structural stability. These results corroborate those of Blanco-Canqui (2017), who states that biochar incorporation enhances soil resistance to erosion and promotes carbon sequestration.

1.4.2.3. Implications for the Restoration of Degraded Lands

The increase in microbial and enzymatic activity promotes the biodegradation of organic matter and the recycling of essential nutrients for plants. Improved soil structure allows better root anchorage and reduces water stress, a key factor for restoring Sahelian soils. The positive effect on water retention and soil aggregation helps reduce erosion and enhances the resilience of degraded soils to climate change.

Thus, integrating biochar-compost is an effective and sustainable strategy to improve soil fertility and structure in arid and semi-arid environments.

Biochar-compost stimulated microbial activity more than compost alone, with microbial biomass reaching 540 µg C/g of soil, compared to 450 µg C/g of soil in composted soils. However, non-degraded soils had even higher microbial biomass (600 µg C/g of soil). This increase in biochar-amended soils is linked to the improved ecological niche for microorganisms, enhancing organic matter degradation and improving soil nutrient properties (Thies & Rillig, 2009).

Microbial respiration, an indicator of biological activity, was also improved in

biochar-composted soils (3.4 mg CO₂/g/day) compared to compost-only soils (2.8 mg CO₂/g/day), but remained lower than in non-degraded soils (3.6 mg CO₂/g/day). This confirms that biochar stimulates microbial processes in degraded soils, but natural undisturbed soils have higher microbial activity due to their intact ecological balance (Lehmann *et al.*, 2011).

1.4.2.4. Effect on Soil Structure

The effect of biochar-compost on soil structure is significant. Bulk density decreased in biochar-composted soils (1.25 g/cm³), indicating better aeration and porosity compared to compost-only soils (1.30 g/cm³). This improvement in soil structure allows better water infiltration and root penetration (Major *et al.*, 2010).

Total porosity and water retention capacity also showed marked improvements in biochar-composted soils, reaching 48.2% and 29.4%, respectively, compared to compost-only soils (42% and 22.6%) and non-degraded soils (50.5% and 31.5%). This reflects biochar's effect on reducing soil compaction and improving its ability to retain water, which is particularly useful for arid regions like those experiencing Sahelian conditions (Woolf *et al.*, 2010).

The application of biochar-compost in degraded soils presents notable advantages over compost alone. The observed improvements in chemical composition, microbial activity, and soil structure demonstrate that biochar-compost effectively contributes to restoring degraded soils by increasing fertility, nutrient bioavailability, and water retention, which are key factors for enhancing agricultural productivity and soil resilience to climate change.

1.5. Impact on Soil Biodiversity

1.5.1. Improvement of Soil Properties

The following table presents the improvement of soil properties (pH, organic matter, nitrogen, phosphorus, water retention capacity, porosity, etc.) in degraded soils treated with biochar-

compost, compared to degraded soils amended only with compost and non-

degraded soils, after a six-month treatment period.

Table 6: Improvement of Soil Properties

Soil Parameter	Degraded Soil (Biochar-Compost)	Degraded Soil (Compost Only)	Non-Degraded Soil
pH (H ₂ O)	6.7 ± 0.4	5.9 ± 0.3	7.2 ± 0.2
Organic Matter (%)	2.8 ± 0.2	1.7 ± 0.1	3.5 ± 0.4
Total Nitrogen (g/kg)	0.15 ± 0.02	0.09 ± 0.01	0.18 ± 0.02
Available Phosphorus (mg/kg)	11.2 ± 1.1	7.8 ± 0.8	12.0 ± 1.5
Microbial Biomass (µg C/g soil)	540 ± 40	450 ± 35	600 ± 50
Microbial Respiration (mg CO ₂ /g/day)	3.4 ± 0.5	2.8 ± 0.4	3.6 ± 0.3
Bulk Density (g/cm ³)	1.25 ± 0.06	1.30 ± 0.05	1.18 ± 0.04
Total Porosity (%)	48.2 ± 2.5	42.0 ± 3.0	50.5 ± 2.8
Water Retention Capacity (%)	29.4 ± 2.1	22.6 ± 1.8	31.5 ± 3.0
Soil Aggregation (%)	64.5 ± 4.0	58.5 ± 3.5	68.0 ± 4.2

1.5.1.1. Effect of Biochar-Compost on Soil Chemical Composition

1.5.1.1.1. Soil pH

The increase in pH in soils treated with biochar-compost (6.7) compared to compost-only soils (5.9) indicates an alkalizing effect of biochar, which is particularly important for acidic soils (Lehmann et al., 2015). A higher pH can improve nutrient availability, especially phosphorus, which is often immobilized in acidic soils.

1.5.1.1.2. Organic Matter

Biochar-composted soils showed a significant increase in organic matter (2.8%) compared to compost-only soils

(1.7%). This phenomenon is linked to the addition of stable carbon by biochar, which helps sequester carbon and stabilize organic matter in the soil (Lehmann & Joseph, 2015). Non-degraded soils contain more organic matter (3.5%), reflecting a better ecological balance.

1.6. Impact of Biochar-Compost Seeding Technique on Soil Biodiversity

The following table presents the impact on soil biodiversity in terms of microbial diversity, soil fauna (earthworms, insects), and fungal biodiversity in degraded soils treated with biochar-compost compared to soils treated with compost alone and non-degraded soils after a period of 6 months.

Table 7: Impact on Soil Biodiversity

Biodiversity Parameter	Degraded Soil (Biochar-Compost)	Degraded Soil (Compost Only)	Non-Degraded Soil
Bacterial species richness (N°. of species/100 g of soil)	23 ± 4	18 ± 3	25 ± 5
Fungal species richness (N°. of species/100 g of soil)	14 ± 2	10 ± 2	15 ± 3
Earthworm abundance (individuals/m ²)	22 ± 3	18 ± 2	25 ± 4
Soil insect abundance (individuals/m ²)	125 ± 15	95 ± 10	130 ± 12
Shannon Diversity Index (H')	2.8 ± 0.3	2.4 ± 0.2	3.0 ± 0.2

Total species richness (N°. of species/100 g of soil)	37 ± 5	30 ± 4	40 ± 6
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1.6.1. Impact on Microbial Species Richness

1.6.1.1. Bacterial and Fungal Species Richness

Soils amended with biochar-compost exhibit greater bacterial species richness (23 species/100 g of soil) and fungal species richness (14 species/100 g of soil) compared to soils treated with compost alone (18 species for bacteria and 10 species for fungi). Biochar enhances microbial diversity by providing a suitable environment for the adaptation and growth of microorganisms, especially in degraded soils where conditions may be challenging for microbial life. It also offers adsorption sites and protection for microorganisms, enabling them to survive under less favorable conditions (Lehmann et al., 2011). This increased microbial diversity is also a key factor in soil nutrient remineralization and mobilization.

1.6.1.2. Impact on Soil Fauna

1.6.1.2.1. Earthworms and Soil Insects

Earthworm abundance is higher in soils amended with biochar-compost (22 individuals/m²) than in compost-only soils (18 individuals/m²), but still lower than in non-degraded soils (25 individuals/m²). Earthworms are bio-indicators of soil health, and their presence and abundance in biochar-composted soils suggest an improvement in soil structure and favorable living conditions for soil fauna (Edwards, 2004).

Similarly, soil insect abundance in biochar-composted soils (125 individuals/m²) is higher than in compost-treated soils (95 individuals/m²), which can be attributed to the diversity of ecological niches created by improved soil structure. This increase in soil fauna biodiversity may lead to better regulation of pathogenic microorganism populations and enhanced organic matter decomposition (Carter et al., 2007).

1.6.1.2.2. Shannon Diversity Index (H')

The Shannon Diversity Index is higher in biochar-composted soils (2.8) than in compost-only soils (2.4), but lower than in non-degraded soils (3.0). This index is an indicator of species diversity within an ecosystem. A higher index suggests greater biodiversity, indicating a better ecological balance in biochar-composted soils.

1.6.1.2.3. Total Species Richness

Species richness in biochar-compost-treated soils is also higher (37 species/100 g of soil) than in compost-only soils (30 species/100 g of soil). This reflects biochar's ability to promote greater biological diversity, particularly among microorganisms and soil fauna, by providing a more favorable environment for species establishment and reproduction (Kameyama et al., 2017).

The results show that applying biochar-compost to degraded soils improves soil biodiversity by increasing species richness and microbial diversity, as well as soil fauna (earthworms and insects). This enhancement of both microbial and faunal biodiversity is crucial for rehabilitating degraded soils, as it promotes a more stable ecological balance and enhances natural soil fertilization processes. Additionally, biochar appears to create more favorable living conditions in degraded soils, supporting the idea that biochar-compost amendment is an effective method for ecological land restoration.

1.7. Additional Analysis of Plant Responses to Soil Amendments

The following table presents results regarding the impact of biochar-compost amendments on plant responses, particularly in terms of seedling growth, root development, and resistance to stress conditions (drought) compared to non-

amended soils and compost-only amended soils.

Table 8: Plant Responses to Soil Amendments

Observed Parameter	Degraded Soil (Biochar-Compost)	Degraded Soil (Compost Only)	Non-Degraded Soil (Control)
Seedling height (cm)	30.2 ± 4.1	23.5 ± 3.2	35.0 ± 5.5
Root length (cm)	25.3 ± 3.6	20.1 ± 3.1	30.4 ± 4.2
Fresh weight of seedlings (g)	5.8 ± 1.0	4.4 ± 0.8	6.3 ± 1.2
Dry weight of seedlings (g)	2.1 ± 0.3	1.7 ± 0.2	2.4 ± 0.4
Survival rate (%)	92 ± 4	80 ± 5	95 ± 2
Resistance to water stress (%)	85 ± 3	75 ± 4	90 ± 2
Biomass production (g/m ²)	15.3 ± 2.1	12.0 ± 1.5	18.5 ± 2.4

The amendment of degraded soils with biochar-compost has a substantial positive effect on plant responses, promoting better plant growth, enhanced root development, increased resistance to water stress, and improved seedling survival. These results demonstrate that biochar-compost can play a crucial role in restoring degraded lands by providing a more favorable environment for plant growth, which is essential for long-term ecological rehabilitation projects.

2. Discussion

2.1. Role of Biochar-Compost in Seed Germination and Plant Growth

The results confirm that seed coating with biochar-compost significantly improves seed germination and plant growth, corroborating the work of Hardy *et al.* (2020), who demonstrated that biochar enhances moisture retention around seeds, thus reducing water stress during the early growth stages.

Other studies (Lehmann & Joseph, 2015) show that biochar improves nutrient availability by limiting their leaching, which may explain why seedlings from coated seeds exhibited faster and more vigorous growth compared to other treatments.

2.2. Beneficial Effects of Biochar-Compost on Degraded Soils

The increase in organic matter and water retention in the soils confirms the role of biochar as an enhancer of physical and chemical soil properties (Glaser *et al.*, 2002). In particular, the improvement in pH observed in this study aligns with the results of Biederman & Harpole (2013), who showed that applying biochar to acidic soils contributes to a gradual neutralization of acidity, thus promoting better nutrient uptake by plants.

Moreover, the effect of biochar-compost on microbial biodiversity suggests that it acts as a substrate promoting the establishment of nitrogen-fixing bacteria and mycorrhizal fungi. This observation supports the findings of Woolf *et al.* (2010), who stated that biochar stimulates soil biological activity by providing a stable habitat for beneficial microorganisms.

2.3. Implications for Land Restoration

The improvement in plant growth and soil properties due to biochar-compost suggests that this seeding technique could be a sustainable solution for the restoration of degraded lands in the Sahelian zone. Lal (2015) emphasizes the importance of integrating agroecological approaches and organic amendments into soil rehabilitation strategies to maximize the resilience of agroecosystems to climate change.

Finally, although the results are promising, long-term studies are necessary to assess the sustainability of the observed effects and test this approach at a larger scale under various agro-climatic conditions.

Conclusion and Recommendations

1. Conclusion

The results of this study confirm that seeding assisted by coating seeds with biochar-compost is an effective approach to improve seed germination, promote seedling growth, and restore degraded soils. The combined use of biochar and compost creates a favorable environment by increasing water retention, stabilizing pH, and stimulating soil biological activity. Specifically, the seeds coated with biochar-compost showed:

- A 30% higher germination rate compared to non-coated seeds,
- Faster and more vigorous growth,
- Improved soil fertility by increasing organic matter, water retention, and microbial diversity.

Additionally, this technique holds great potential for adoption in the Sahelian region, where challenges related to land degradation, desertification, and climate change require sustainable agroecological solutions. However, despite these benefits, some limitations must be considered, including:

- The cost and availability of biochar on a large scale,
- The need for long-term studies to assess the sustainability of the effects,
- Adapting the technique depending on soil types and plant species used.

2. Recommendations

To maximize the effectiveness of this technique and facilitate its adoption by rural communities, several recommendations can be made:

a) Technical Optimization

- Standardize seed coating protocols according to plant species and soil types to improve germination and growth efficiency.
- Explore other sources of biochar from local agricultural waste (peanut shells, cotton residues, rice husks) to reduce production costs.
- Integrate beneficial microorganisms (e.g., mycorrhizae, nitrogen-fixing bacteria) into coatings to enhance plant resilience to water stress.

b) Large-Scale Application and Local Adoption

- Raise awareness and train farmers and rural communities on the benefits of this technique and biochar-compost production methods.
- Develop pilot projects in different agro-ecological zones to test the reproducibility of results and adapt the technique to local realities.
- Encourage the integration of this approach into land restoration and desertification control policies, in collaboration with government institutions and environmental NGOs.

c) Research and Long-Term Monitoring

- Evaluate the long-term environmental impacts, particularly on carbon sequestration and soil biodiversity.
- Analyze the economic viability of this technique compared to conventional reforestation and soil amendment methods.
- Explore combinations with other agroecological practices such as agroforestry and direct seeding under plant cover to maximize positive environmental effects.

Seed-assisted seeding with biochar-compost seed coating represents a promising innovation for restoring degraded lands, especially in the Sahelian

zone. Its adoption could contribute to combating desertification, regenerating ecosystems, and improving the livelihoods of local populations. However, further efforts are required to optimize its application, reduce costs, and facilitate its widespread dissemination.

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