Synergistic effects of coconut frond biochar and liming materials on physical properties of laterite soils

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ABSTRACT

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| **Aims:** The impact of co-applying coconut frond biochar (CFB) with liming materials such as dolomite or calcium silicate (CS) on soil physical properties was investigated in a laterite soil, Kerala, India, with tomato variety Vellayani Vijai as a test crop.**Place and Duration of Study:** Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala Agricultural University, India between June 2023 and September 2023.**Methodology:** The treatments included CFB at 10 t ha-1 with CS as LR, CFB at 10 t ha-1 with dolomite as per LR each in combination with NPK as per KAU package of practices (KAU POP) recommendation, KAU POP (FYM at 20 t ha-1 + 75:40:25 kg NPK ha-1 + lime at 500 kg ha-1), KAU organic POP (FYM at 25 t ha-1 + poultry manure (PM) at 1 t ha-1+ lime at 500 kg ha-1) and absolute control. **Results:** Application of CFB at 10 t ha-1 with dolomite or CS as per LR significantly improved soil physical properties compared to KAU POP and KAU organic POP. Compared to KAU POP, CFB-based treatments reduced bulk density up to 7.3, 3.47 and 0.68%, increased porosity up to 16.94, 6.35 and 5.33%, improved water stable aggregates up to 8.55, 13.81 and 19.13%, and enhanced water holding capacity up to 41.94, 23.94 and 19.53% at soil depths of 0-15 ,15-30 and 30-60 cm, respectively. Compared to KAU Organic POP, CFB-based treatments showed similar improvements.**Conclusion:** These results indicate that integrating CFB with liming materials can effectively enhance soil structure, moisture retention, and overall soil health in laterite soils, making it a recommended practice for farmers to improve crop productivity and long-term agricultural sustainability. |

*Keywords: Coconut frond biochar, calcium silicate, dolomite, physical properties, laterite soil.*

1. INTRODUCTION

Soil physical properties play a fundamental role in determining its suitability for agricultural production. These properties regulate soil structure, water retention, nutrient dynamics, root penetration and aeration, which are essential for plant growth and development (Phogat *et* al., 2015). Application of organic amendments significantly improves soil physical properties. Application of FYM at 20 Mg ha⁻¹ reduced bulk density by 5.57% and increased hydraulic conductivity by 35.5% compared to recommended NPK (Khan et al., 2010).Applying cattle manure significantly reduced soil bulk density (Rasoulzadeh and Yaghoubi, 2010). Green gram and sesbania green manure reduced soil bulk density by 0.03–0.07 Mg m⁻³ (Mandal et al., 2003).

Traditionally, organic materials such as animal manure, compost, crop residues, sewage sludge, and municipal waste have been used for improving these properties. In recent years, industrial by-products such as fly ash, gypsum, and lime, along with agro-industrial residues like biochar and molasses, have gained attention for their potential to improve soil structure, reduce compaction and enhance aeration. (Rizwan et al., 2018). Biochar is a carbon-rich material produced through the thermochemical decomposition of biomass under oxygen-limited conditions. It improves soil physical properties by improving porosity, water retention, and aggregate stability while also contributing to long-term carbon sequestration. Biochar is an effective alternative to organic and inorganic amendments, as it improves soil cation exchange capacity (CEC) and enhances soil nutrient availability (El-Naggar et al., 2018). Several studies have reported that biochar improves soil physical, chemical and biological properties, leading to higher crop yields. Soil porosity, permeability and saturated hydraulic conductivity increased by applying biochar (Oguntunde *et al*., 2008). Applying 25 g kg-1 biochar in silty soil reduced the bulk density from 1.52 g cm−3 to 1.33 g cm−3. Application of wood biochar at 20 t ha⁻¹ resulted in a 28–140 % increase in maize yield compared to the unamended control (Major et al., 2010). Similar results were reported by Khaled et al. (2019) and Kalu et al. (2021).

Liming enhances soil physical, chemical, and biological properties by improving soil structure, increasing pH, reducing aluminium toxicity, and promoting microbial activity, thereby creating more favourable environment for plant growth and nutrient availability (Bhindhu *et al*., 2018; Crusciol *et al*., 2017; Crusciol *et al*., 2014; Lollato *et al*., 2013; Kovacevic and Ratija, 2010). The laterite soils of Kerala are naturally acidic, with low CEC and poor retention of bases. Therefore, an integrated approach that combines biochar with liming materials is essential for enhancing soil physical properties and improving crop productivity of laterite soils. This article compares the effect of co-applying biochar with two different liming materials viz. calcium silicate or dolomite along with N, P and K, and KAU POP and KAU organic POP treatments on physical properties at different soil depths.

2. experimental details

***2.1 Design and layout of the experiment***

The field experiment was conducted, with tomato variety Vellayani Vijaias the test crop at College of Agriculture, Vellayani, Kerala, India**.** The experimental site was located at 80 25ʹ36ʺ North latitude and 760 59 ʹ 17 ʺ East longitude, with an altitude of 29 m above mean sea level. The crop was grown from June to September 2023. During this period, temperatures ranged from 26.5°C to 32°C during the day and 22.1°C to 24.3°C at night. The total rainfall recorded was 121 mm. Relative humidity varied between 74.7% and 95.1% in the morning (7 AM) and 71.1% to 86.3% in the afternoon (2 PM).

The soil at the experimental site belonged to the Vellayani series and was classified as loamy kaolinitic isohyperthermic Typic Kandiustult. The field experiment followed a Randomized Block Design (RBD) with five treatments and three replications. The treatments were T1: CFB at 10 t ha-1 with CS as LR (2325.18 kg ha-1), T2: CFB at 10 t ha-1 with dolomite as per LR (1088.7 kg ha-1), each in combination with NPK as per POP (75:40:25 kg NPK ha-1), T3: KAU POP (FYM at 20 t ha-1 + 75:40:25 kg NPK ha-1 + lime at 500 kg ha-1) (KAU, 2016), T4: KAU organic POP (FYM at 25 t ha-1 + poultry manure at 1 t ha-1+ lime at 500 kg ha-1) (KAU, 2009) and T5: absolute control. The field was prepared with beds measuring 2.4 m × 2.4 m (l ×b) and 25 cm height, maintaining a spacing of 30 cm between beds to serve as drainage channels.

Organic and inorganic amendments were incorporated into the field 14 days before transplanting the seedlings. The recommended fertilizer dose for tomato was 75:40:25 kg ha⁻¹ NPK (KAU, 2016). Half of the nitrogen (N), full dose of phosphorus (P), and half of the potassium (K) were applied as a basal dose. One-fourth of the N and the remaining half of the K were applied 30 days after planting, while the final one-fourth of the N was applied two months after planting. The fertilizers used included urea, rajphos and muriate of potash. In the KAU organic POP treatment, top dressing was applied at 7–10-day intervals using poultry manure at 1 t ha⁻¹.

**2.2 Planting tomatoes**

 Tomato seeds were sown in pro trays and irrigated at two-day intervals. Seedlings, 21 days old, were transplanted into the main field two weeks after amendment application. They were spaced 60 cm apart in the beds and irrigated as needed.

**2.3 Collection of Ameliorants**

The ameliorant calcium silicate was purchased from Astrra Chemicals, Tamil Nadu. Poultry manure and FYM were obtained from the College of Agriculture, Vellayani. Biochar was produced through slow pyrolysis of coconut fronds at College of Agriculture, Vellayani.

**2.4 Characterization of soil and organic amendments**

Soil samples were collected from the experimental site at three depths: 0–15, 15–30 and 30–60 cm. Soil properties were analysed before and after the experiment using standard procedures. Soil texture was determined by the international pipette method (Piper, 1966). Bulk density and particle density were measured using the undisturbed core sample method and the pycnometer method, respectively (Black et al., 1965). Aggregate analysis was conducted using Yoder’s wet sieving method (Gupta and Dakshinamurthy, 1980). The Keen-Raczkowski Box method was used to determine the maximum water-holding capacity of the soil (Piper, 1966).

All the organic amendments were analyzed for bulk density (BD), pH and total carbon (C) and nitrogen (N) (Table 1). Total C and N were determined by using CHNS analyzer (Byers *et al*., 1978). BD was calculated using cylinder method (Piper, 1966). pH was measured using 1:5 soil water suspension (Jackson, 1973).

Table 1: Physical and chemical properties of organic amendments

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| --- | --- | --- | --- | --- |
| **Sl. No.** | **Properties** | **FYM** | **PM** | **CFB** |
| 1. | pH | 7.52 | 7.64 | 10.70 |
| 2. | Bulk density (Mg m-3) | 0.43 | 0.43 | 0.36 |
| 3. | Total C (%) | 23.42 | 20.81 | 41.11 |
| 4. | Total N (%) | 1.07 | 2.97 | 0.44 |
| 5. | C: N ratio | 21.78 | 7.01 | 93.43 |

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3. results and discussion

. Soil collected from the experimental field was acidic in reaction with an initial pH of 5.01, 4.81 and 4.73. The soil was sandy clay loam with an initial bulk density (BD) of 1.43, 1.51 and 1.56 Mg m-3, particle density (PD) of 2.25, 2.23 and 2.21 Mg m-3, porosity of 36.44, 32.29 and 29.41 %, water stable aggregates (WSA) of 43.11, 41.24 and 34.47 % and water holding capacity (WHC) of 29.31, 28.3 and 27.78 % at 0-15, 15-30 and 30-60 cm depth of soil, respectively. Soil collected from experimental site at different depths (0-15, 15-30 and 30-60 cm) at the end of the crop growth period were analyzed and the results obtained are presented below.

**3.1 Soil physical properties**

**3.1.1 Bulk density**

There was a significant reduction in bulk density of surface and subsurface soil applied with different treatments (Table 2). Significantly lowest (1.27 Mg m-3) BD for 0-15 cm depth of soil was obtained for T2 receiving CFB @ 10 t ha-1 along with CS as per LR followed by T1 receiving CFB @ 10 t ha-1 with dolomite as per LR and KAU organic POP, with a value of 1.32 Mg m-3. T2 gave the lowest value (1.39 Mg m-3) for BD at 15-30 cm depth of soil, and it was on par with T1 (1.41 Mg m-3) which in turn on par with KAU organic POP (1.42 Mg m-3). KAU POP (1.44 Mg m-3) was on par with KAU organic POP for BD at 15-30 cm depth of soil. T1 recorded significantly lowest value (1.45 Mg m-3) of BD for 30-60 cm depth of soil. T2 (1.47 Mg m-3) was on turn on par with KAU POP and KAU organic POP (1.48 Mg m-3) and they were significantly higher than T1 for BD at 30-60 cm depth of soil. The absolute control treatment gave the highest value for BD at all depth of soil.

The bulk density of surface and subsurface soil treated with CFB @ 10 t ha-1 with CS or dolomite as per LR was significantly lower than that of treatments receiving KAU POP and KAU organic POP. BD of soil receiving CFB @ 10 t ha⁻¹ with Dolomite as per LR showed a reduction of 3.65, 2.08 and 2.03% at 0-15, 15-30 and 30-60 cm depths, respectively, compared to KAU POP, while the reduction compared to KAU Organic POP was 0.00, 0.70 and 2.03% at the corresponding depths. Similarly, BD in T2 (CFB @ 10 t ha⁻¹ + CS as per LR + NPK as per POP) decreased by 7.30, 3.47 and 0.68% compared to KAU POP, and by 3.79, 2.11 and 0.68% compared to KAU Organic POP at 0-15, 15-30 and 30-60 cm depths of soil, respectively.

BD of CFB was much less than FYM, PM and the mineral soil used for the present study. The reduction in BD due to biochar application could primarily be attributed to the low BD of the material itself and to the increase in soil organic matter and pore space consequent to its application. The initial BD of the experimental soil (1.32 Mg m-3) decreased to 1.23 Mg m-3 after the application of coconut husk and shell biochar in a sandy clay loam soil at 10 t ha-1 (Rajakumar, 2019). Significant decrease in BD of the biochar applied fields was also reported by Dainy (2015) and Rajalekshmi (2018).

Table 2. Effect of treatments on bulk density (Mg m-3) at different depths of post harvest soil

|  |  |  |  |
| --- | --- | --- | --- |
|  **Treatments** | **0-15 cm** | **15-30 cm** | **30-60 cm** |
|  T1: CFB at 10 t ha-1 + dolomite as per LR+ NPK as per POP | 1.32 ± 0.01c | 1.41 ± 0.01b | 1.45 ± 0.01c |
|  T2: CFB at 10 t ha-1 + CS as per LR + NPK as per POP | 1.27 ± 0.02d  | 1.39 ± 0.02c  | 1.47 ± 0.00b  |
|  T3: KAU POP | 1.37 ± 0.02b | 1.44 ± 0.02b | 1.48 ± 0.01b |
|  T4: KAU organic POP | 1.32 ± 0.01c | 1.42 ± 0.01b | 1.48 ± 0.00c |
|  T5: Absolute control | 1.41 ± 0.01a | 1.49 ± 0.01a | 1.51 ± 0.02a |
|  SEm± | 0.008 | 0.007 | 0.005 |
|  CD (0.05) | 0.026 | 0.023 | 0.016 |

**3.1.2 Porosity**

 Porosity is considerably increased by the application of treatments (Table 3). Significantly highest value (45.91 %) at 0-15 cm depth of soil was observed for T2 receiving CFB @ 10 t ha-1 along with CS as per LR followed by T1 receiving CFB @ 10 t ha-1 with dolomite as per LR (42.99 %) which was on par with KAU organic POP (41.18 %). T2 recorded significantly highest value (37.52 %) for porosity at 15.-30 cm followed by KAU organic POP (36.11 %) and it was on par with T1 (36.08 %) and KAU POP (35.28 %). Porosity of T1 showed significantly highest value (34.19 %) at 30-60 cm depth of soil which was on par with T2 (34.16 %). KAU organic POP (33.17 %) was on par with KAU POP (32.43 %), and they were significantly lower than T1 and T2. The absolute control treatment recorded the lowest value at all depths.

The treatments receiving CFB at 10 t ha⁻¹ with CS or dolomite as per LR, recorded significantly higher porosity at 0–15, 15–30 and 30–60 cm depths of soil, compared to KAU POP and KAU organic POP. T1 showed an increase in porosity by 9.50, 2.27 and 5.43% at 0-15, 15-30 and 30-60 cm depths of soil, respectively, compared to KAU POP, and by 4.40%, a slight decrease of 0.08%, and 3.08% at the respective depths compared to KAU Organic POP. Similarly, T2 exhibited an increase of 16.94, 6.35 and 5.33% at 0-15, 15-30 and 30-60 cm depths, respectively, compared to KAU POP, and an increase of 11.49, 3.90 and 2.98% at the respective depths compared to KAU Organic POP.

Improvement in porosity of soil after biochar application could be due to the pore contribution from the highly porous biochar material, alteration of the pore system by creating packing or pores and improving soil aggregate stability (Hardie *et al.*, 2014). Application of tender coconut husk biochar increased the porosity from 43.1 to 45.6 %, compared to control (Nagula *et al*., 2021). Application of biochar increased soil porosity by 8.4 % (Omondi *et al*., 2016). Similar result was recorded by Sun and Lu (2014). Liming can also improve soil porosity. Structural changes brought about by liming in the soil result in an increase in the populations of earthworms and enchytraeids, leading to a rise in soil porosity (Grieve *et al*., 2005). Ferreira *et al*., (2018) observed a significant difference in soil porosity and the number of pores between different soil layers due to the application of lime. Soil microporosity and water retention at 0-10 cm depth of soil increased with application of lime at 15 t ha-1, compared to the soil without lime (Ferreira *et al*., 2019). In this study, application of inorganic amendments like CS or dolomite or lime as per LR along with organic amendments (CFB at 10 t ha-1, FYM at 20 t ha-1 or PM at 1 t ha-1) might have improved the soil porosity compared to control.

Table 3. Effect of treatments on porosity (%) at different depths of post harvest soil

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **0-15 cm** | **15-30 cm** | **30-60 cm** |
| T1: CFB at 10 t ha-1 + dolomite as per LR+ NPK as per POP | 50.27 ±1.02a | 41.31 ± 1.13a | 37.45 ± 0.86a |
| T2: CFB at 10 t ha-1 + CS as per LR + NPK as per POP  | 51.27 ± 1.16a | 41.08 ± 0.89a | 37.55 ± 0.34a |
| T3: KAU POP | 36.13 ± 0.02b | 33.15 ± 0.51b | 31.42 ± 0.16b |
| T4: KAU organic POP | 38.63 ± 4.55b | 32.41 ± 1.13b | 32.02 ± 0.86b |
| T5: Absolute control | 29.23 ± 0.76c | 27.27 ± 0.94c | 26.89 ± 1.05c |
| SEm± | 1.242 | 0.584 | 0.468 |
| CD (0.05) | 4.05 | 1.905 | 1.526 |

**3.1.3 Water stable aggregates**

The data presented in table 4 indicates that WSA was significantly influenced by the treatments. T1 receiving CFB @ 10 t ha-1 with dolomite as per LR registered the highest values for WSA at 0-15 and 15-30 cm depth soil (58.32 and 51.30 %, respectively) and it was on par with T2 receiving CFB @ 10 t ha-1 with CS as per LR (57.32 and 50.73 %, respectively). The highest value for WSA at 30-60 cm depth of soil was observed for T2 (45.11 %) which was on par with T1 (44.22 %). KAU POP was on par with KAU organic POP for WSA at 0-15 (52.80 and 52.58 %, respectively), 15-30 (44.57 and 46.36 %, respectively) and 30-60 cm (37.87 and 39.32 %, respectively) depths and they were significantly lower than T1 and T2. The lowest value was registered by the absolute control treatment at all depths of soil.

Increase in WSA by the combined application of organic and inorganic amendment at surface and subsurface soil might be due to the improvement in organic matter content and Ca and Mg ions which facilitates the flocculation and cementation of soil. Organic amendments can bind with soil particles by electrostatic attraction, leading to the formation of micro- aggregates (Six *et al*., 2004). Application of CFB @ 10 t ha-1 with CS or dolomite as per LR gave significantly higher values for WSA, compared to KAU POP and KAU organic POP, at 0-15, 15-30 and 30-60 cm depths of soil. Treatment receiving CFB @ 10 t ha⁻¹ with dolomite as per LR resulted in an increase in WSA by 10.45, 15.08 and 16.81 % at 0-15, 15-30 and 30-60 cm depths, respectively, compared to KAU POP, and by 10.92, 10.66 and 12.47 % at the respective depths compared to KAU Organic POP. Similarly T2 receiving CFB @ 10 t ha⁻¹ with CS as per LR exhibited an increase of 8.55, 13.81 and 19.13 % at 0-15, 15-30 and 30-60 cm depths, respectively, compared to KAU POP, and an increase of 9.01, 9.43 and 14.71 % at the respective depths compared to KAU Organic POP.

Biochar influences soil aggregation due to its interaction with soil organic matter, minerals and microorganisms. It contains cations that can be joined by the means of cationic bridges with clay and organic particles and thus creating a favourable soil structure condition (Bronick and Lal, 2005). Labile organic matter on the surfaces of biochar acts as a substrate for microorganisms, enhancing their excretion of mucilage, which in turn helps to create stable soil aggregates (Liang *et al*., 2008). Aggregation may intensify over time resulting in the formation of stable soil structure. Application of coconut shell biochar showed a 40.3 % increase in WSA in a sandy loam soil, compared to control (Kumar and singh*.* 2020). Similar results were reported by Blanco-Canqui (2017).

Liming in acid soils improve soil aggregate and structural stability by the cementing action of Ca2+ and carbonates with organic matter (Six *et al*., 1998). Increase in pH because of liming can improve flocculation of clay by compressing the double layer between clay particles (Haynes and Naidu, 1998) and precipitation of Al hydroxy polymers, which are excellent flocculating agents for clay particles (Rengasamy and Oades, 1978). Aggregate stability was reported to significantly increase by the application of lime on a clayey soil (Blomquist et al., 2018). The application of cured manure and CaCl2 improved WSA by 15.7 % compared to the control (Wuddivira and Camps-Roach, 2007). Combined application of lime and PG increased the amount of WSA by 82, 145, 273 and 152 % at 5-10, 10-20, 20-40 and 40-60 cm of soil, respectively (Carmeis *et al*., 2016).

Table 4. Effect of treatments on water stable aggregates (%) at different depths of post harvest soil

|  |  |  |  |
| --- | --- | --- | --- |
|  **Treatments** | **0-15 cm** | **15-30 cm** | **30-60 cm** |
|  T1: CFB at 10 t ha-1 + dolomite as per LR+ NPK as per POP | 42.99 ± 0.47b | 36.08 ± 0.30b | 34.19 ± 0.30a |
|  T2: CFB at10 t ha-1 + CS as per LR + NPK as per POP | 45.91 ± 1.67a  | 37.52 ± 0.69a  | 34.16 ± 0.21a |
|  T3: KAU POP | 39.26 ± 0.68d | 35.28 ± 0.68b | 32.43 ± 0.27b |
|  T4: KAU organic POP | 41.18 ± 0.25c | 36.11 ± 0.25b | 33.17 ± 0.11b |
|  T8: Absolute control | 37.19 ± 0.51e | 33.27 ± 0.28c | 31.82 ± 0.69c |
|  SEm± | 0.553 | 0.312 | 0.221 |
|  CD (0.05) | 1.804 | 1.017 | 0.722 |

**3.1.4 Water holding capacity**

Significantly highest values for WHC at 0-15 and 30-60 cm depths of soil were observed for T2 (CFB @ 10 t ha-1 + CS as per LR + NPK as per POP) (51.27 and 37.55 %, respectively) which were on par with T1 (CFB @ 10 t ha-1 + dolomite as per LR + NPK as per POP) (50.27 and 37.45 % respectively). The WHC of T1 (41.31 %) and T2 (41.08 %) were on par with each other and gave the highest value at 15-30 cm depth of soil. WHC of KAU POP and KAU organic POPwere on par with each other at 0-15, 15-30 and 30-60 cm depth of soil. The absolute control recorded significantly lowest value for WHC at all depths of soil.

Combined application of CFB at 10 t ha⁻¹ with dolomite or CS as per LR significantly increased the water holding capacity at soil depths of 0–15, 15–30 and 30–60 cm compared to KAU POP and KAU organic POP. The application of CFB @ 10 t ha⁻¹ with dolomite as per LR enhanced WSA by 39.10, 24.64 and 19.18 % at soil depths of 0-15 15-30 and 30-60 cm, respectively, in comparison to KAU POP. Similarly, it showed an increase of 30.02, 27.41 and 17.01 % at the respective depths relative to KAU Organic POP. Likewise, T2 (CFB @ 10 t ha⁻¹ + CS as per LR + NPK as per POP) led to an improvement of 41.94, 23.94 and 19.53% at 0-15, 15-30 and 30-60 cm, respectively, compared to KAU POP, while also increasing WHC by32.73, 26.75and 17.28 % at the corresponding depths relative to KAU Organic POP.

High porosity and specific surface area of biochar improve the water permeability of soil, WHC and change the water residence time and flow path (Abrol *et al*., 2016). Production of humic substances in soil after the application of biochar is another reason for the improved WHC (Piccolo *et al*., 1996). Jabin (2022) observed increase in WHC by 52.55 % in a laterite soil after the addition of paddy husk biochar @ 30 t ha-1. Sokchea and Preston (2011) and Karhu *et al*. (2011) also recorded positive influence on WHC by the application of biochar.

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments** | **0-15 cm** | **15-30 cm** | **30-60 cm** |
|  T1: CFB at10 t ha-1 + dolomite as per LR+ NPK as per POP | 58.32 ± 1.31a | 51.30 ± 1.01a | 44.22 ± 1.64ab |
|  T2: CFB at 10 t ha-1 + CS as per LR + NPK as per POP | 57.32 ± 0.50a | 50.73 ± 0.61ab | 45.11 ± 2.47a |
|  T3: KAU POP | 52.80 ± 0.67b | 44.57 ± 0.54b | 37.87 ± 1.38b |
|  T4: KAU organic POP | 52.58 ± 2.71a | 46.36 ± 1.15a | 39.32 ± 1.08a |
|  T5: Absolute control | 44.01 ± 0.64c | 40.89 ± 1.73c | 33.24 ± 0.87c |
|  SEm± | 0.838 | 0.694 | 1.018 |
|  CD (0.05) | 2.734 | 2.264 | 3.32 |

Table 5. Effect of treatments on water holding capacity (%) at different depths of post harvest soil

4. Conclusion

The application of coconut frond biochar at 10 t ha⁻¹, combined with either dolomite or calcium silicate as per LR significantly improved soil physical properties compared to KAU POP and KAU Organic POP. The reduction in bulk density and improvement of porosity, water stable aggregates and water holding capacity indicate that biochar plays a crucial role in improving soil structure and water retention. These benefits are attributed to the highly porous nature of biochar, which enhances aeration, water retention, and microbial activity, as well as its high surface area and CEC which facilitate soil aggregation and nutrient retention. Additionally, the liming effect of dolomite and calcium silicate improved soil structure by reducing soil acidity, increasing Ca²⁺ and Mg²⁺ availability, and enhancing flocculation and aggregate stability. The combined application of organic and inorganic amendments further promoted soil aggregation and stability, creating a more favourable soil environment. Overall, this study underscores the potential of biochar-based amendments in enhancing soil physical properties, thereby contributing to sustainable soil management and improved crop productivity in acidic soils.

Ethical approval

This research has been conducted in an ethical and responsible manner and is in full compliance with all relevant codes of experimentation and legislation.

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