East African Journal of Forestry & Agroforestry
eajfa.eanso.org
Volume 8, Issue 1, 2025
Print ISSN: 2707-4315 | Online ISSN: 2707-4323
Title DOI: https://doi.org/10.37284/2707-4323

EANSO
EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Effect of Soil Priming on Degraded Forest Soil and Early Growth of *Garcinia kola* (Heckel) in Derived Savannah Belt, Delta State, Nigeria

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Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

Date Published:

11 July 2025

Keywords:

Cation Exchange Capacity, Forest Soil, Primed Soil Types, Garcinia kola, Germination Rate, Leaf Surface Area.

ABSTRACT

Deforestation poses a serious challenge to tropical soil fertility and complicates the regeneration of degraded forests with recalcitrant indigenous tree species. Soil priming with aquatic ecosystem-enriched matters, for seeds and cytoplasmic activities, supports, offers a nutrient imbuing technique in the tropics. This study investigated the priming capacity of degraded forest soils with diverse aquatic ecosystem sands for the early growth of *Garcinia kola*. Flood Plain (FP), River Sand (RS) and Degraded forest (DS) soils were processed, analyzed for physico-chemical properties and five (5) primed soil types of 25-75, 40-60, 50-50, 75-25, and 75-30 volume/volume with (FP-DS) and (RS-DS) bases formulated to contrast 100 v/v FP, RS and DS for *Garcinia kola* growth. Growth characteristics of seedlings were monitored, and collected data subjected to analysis of variance, while significant means were separated with the Duncan Multiple Range Test at 5%. Results showed significant differences ($p < 0.05$) in pH $_{(CaCl2)}$, exchangeable acidity (DS > RS = FP), total exchangeable base (RS > DS > FP) and effective cation exchange capacity (RS > DS > FP) to influence the highest epigeal germination rate (66.67 ± 24.03%), and largest leaf surface areas (2.83 ± 0.18 cm^2) at 8 and 13 weeks after planting respectively by the 50-50, 40-60 and 25-75v/v FP-DS primed soil types. Thus, underscoring FP-base as a potential augmentation product for the priming of degraded tropical forest soil in pursuit of dormancy breakage, *viz-a-viz* shortened gestation period in the regeneration of *Garcinia kola*.

APA CITATION

Enwelem, E. A., Enaohwo, K. P., Ebere, A. L., Chidera, M. L. & Efemena, D. D. (2025). Effect of Soil Priming on Degraded Forest Soil and Early Growth of *Garcinia kola* (Heckel) in Derived Savannah Belt, Delta State, Nigeria. *East African Journal of Forestry and Agroforestry*, *8*(1), 290-305. https://doi.org/10.37284/eajfa.8.1.3309

CHICAGO CITATION

Enwelem, Egwunatum Anselm, Kator Peter Enaohwo, Anozie Loretta Ebere, Mbagha Lilian Chidera and Dolor Dickens Efemena. 2025. "Effect of Soil Priming on Degraded Forest Soil and Early Growth of *Garcinia kola* (Heckel) in Derived Savannah Belt, Delta State, Nigeria" *East African Journal of Forestry and Agroforestry* 8 (1), 290-305. https://doi.org/10.37284/eajfa.8.1.3309.

Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

HARVARD CITATION

Enwelem, E. A., Enaohwo, K. P., Ebere, A. L., Chidera, M. L. & Efemena, D. D. (2025), "Effect of Soil Priming on Degraded Forest Soil and Early Growth of *Garcinia kola* (Heckel) in Derived Savannah Belt, Delta State, Nigeria", *East African Journal of Forestry and Agroforestry*, 8(1), pp. 290-305. doi: 10.37284/eajfa.8.1.3309.

IEEE CITATION

E. A., Enwelem, K. P., Enaohwo, A. L., Ebere, M. L., Chidera & D. D., Efemena "Effect of Soil Priming on Degraded Forest Soil and Early Growth of *Garcinia kola* (Heckel) in Derived Savannah Belt, Delta State, Nigeria", *EAJFA*, vol. 8, no. 1, pp. 290-305, Jul. 2025.

MLA CITATION

Enwelem, Egwunatum Anselm, Kator Peter Enaohwo, Anozie Loretta Ebere, Mbagha Lilian Chidera & Dolor Dickens Efemena. "Effect of Soil Priming on Degraded Forest Soil and Early Growth of *Garcinia kola* (Heckel) in Derived Savannah Belt, Delta State, Nigeria". *East African Journal of Forestry and Agroforestry*, Vol. 8, no. 1, Jul. 2025, pp. 290-305, doi:10.37284/eajfa.8.1.3309

INTRODUCTION

Tropical forest deforestation and degradation has been characterized with critical threats of nutrient lekeages, losses and increasing decline in soil fertility for agriculture, poverty alleviation, provision of sustainable livelihood options and food security valve over the approximately 30% of indexed as global land and food hunger (FAO 2020; Sileshi, et al., 2020). This is because standing forest tree species contribute extensively through the fall and decomposition of different parts to replenish mined soil nutrients, particularly for recalcitrant seeds with testas that shield inflow of mineral solution to complement cytoplasmic food reserve for early foliar development (Bradford et al., 2017; Bagarinao et al, 2024)

The anthropogenic activities ranging from intensive all year farming on degraded lands to overgrazing of copices and forest succession relics which produce compaction and alteration of soil structural elements and microbial activities has worsened nutrient availability to the detriment of natural regeneration of vegetation, thereby increasing soil erosion susceptibility and leaching in exposed forest ecosystem (Babin et al., 2019; Lal et al, 2020). Furthermore, the perceived solution to emerging soil infertility has been narrowed to inorganic chemical fertiliser applications (Stevens, 2019) in low-yield and nutrient-exhausted soils, along with a misfitted mono-cropping technique (Yang et al., 2021). These essentially have contributed to the depletion of identifiable endemic forest tree species in the lowland ecological zones where local domestication was a potential genetic conservation tool.

Consequetly, nutrient element availabilities became worrisome issues in degraded forest communities due to the perpetuating loss of stand forest vegetation annually as the underlying forest soil are retarded in replenishment (Borrelli et al., 2017; Egwunatum et al., 2020a). The heavy traffic and forest fragmentation pose notable challenges to its regeneration and restoration, particularly in sub-Saharan Africa, due to soil compaction and poor drainage capacity that restrict soil solute nutrient movement, which ultimately denies supports in the early growth of forest tree species (Gupta, 2019; Egwunatum et al., 2020b). Several factors that contribute to soil degradation in the tropical forest regions, primarily driven by agricultural expansion, logging, and urbanisation, are often either minimised or eradicated in the course of such attempts.

The increasing problem of soil degradation has led to the development of various amendments ranging from plant to animal matter and recombination to improve soil structure and fertility, particularly in regions where traditional amendments such as organic compost are scarce or ineffective as a result of poor environmental conditions (Olawale et al., 2023*)*. Recombination sands enhance both physical and chemical properties, particularly soil texture, aeration, and water infiltration properties, which have often reportedly improved favourable internal anchorages for ionisation and microorganisms in plant root development (Li et al., 2021). These prominent methods involve the improvement of

Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

soil structure, fertility, and water retention to facilitate critical early responses to osmotic solutes by forest tree species (Cowie et al., 2011).

Tropical soils have been reported to process some organic matter at different levels, depending on the mineral contents and endophytic micro-organism distributions (Camenzind et al., 2023), to contribute significantly to moisture and critical chemical properties for promoting consistent plant growth (Olawale et al., 2023). Furthermore, the improved soil structure facilitates root penetration, allowing seedlings to establish more extensive and robust root systems. Strong root development is essential for accessing water and nutrients in deeper soil layers, which is particularly important in degraded soils where surface nutrients may be depleted (Lyu et al., 2023). Benefits of recombinant nutrients lie in the possibility of enhancing exchangeable ion complexes in soils through the reaction of incorporated organic materials, releasing essential nutrients for the growth and development of plants, particularly recalcitrant forest seeds (Marthandan et al, 2020; Ewetan et al., 2021).

Garcinia kola (Bitter cola) have been reported to present series of early growth problems at propagation and domestication (Adebayo, et al, 2023), requiring approximately 6-12 months to germinate (Adebisi, 2004; Ajayi & Echi, 2016) due to the dual issues of seed coat and physiological dormancies caused by inherent chemicals in the seed (Oboho & Urughu, 2010). The colossal economic losses associated with attempted propagation and silvicultural trials for domestication and regeneration after such a long time under the soil have contributed negatively to interest in propagation. The increasing importance of *G. kola* in the brevage, pharmacological and cottage industries relying on the fruits, leaves and barks for food, medicine, socio-economic and various benefit (Olayinka, et al, 2021; Dogara et al, 2022) have continued to solicit research efforts at breaking its dormancy and reduced gestation period (Anegbeh, et al, 2008; Alam et al, 2023). Improved nutrient availability at the early phase of growth has been reported to support key physiological processes since that initiates critical biological formwork for plumule and radicle development in earlier photosynthetic, root elongation, and leaf development (Adebisi et al., 2021).

Tropical forests are generally the most productive of all terrestrial ecosystems (Bruijnzeel,1991), mostly occurring on strongly weathered, nutrient-poor soils (Chapin et al., 2002; Sayer & Banin, 2016; Fujii et al., 2017). The high productivity of tropical forests, therefore, can be attributed to their high efficiency in nutrient recycling from the decomposition of organic matter (Bruijnzeel,1991). This, therefore, implies that deforestation and forest degradation potentially rob the soil of needed nutrients over time to stimulate growth. However, with ecological assertion that life began in the sea and known for higher architectural diversity than the terrestrial (Ballinger & Lake, 2006; Irfan & Alatawi, 2019), the chances of novel capacity to both restore degraded soils and equally furnish combatant anti-recalcitrance properties against internal dormancy may become a suitable dual action. It is in this light that most nutrient-inert soil in degraded forest reserves fails to solely support germination and early growth of *Garcinia kola*, probably due to the high sensitivity to soil conditions, particularly in terms of nutrient availability, moisture retention, and root aeration.

It is against this backdrop that soil solids with mineral matters and good nutrient mix efficiencies from the sea and flood plains were examined premised on the ecological foundation that life began from the sea and strictly more architecturally diverse than the terrestrial ecosystem for priming to enhance exchangeable base complexes and create sustainable novel physical-microbial environment based on dual endemism of the humid lowland rainforest and coastal lowland plains (Raven et al, 2005). Hence, this study was conceived to evaluate the influence of the priming capacity of river and flood plain soils on rich-silted but degraded Idumuje-Ugboko Forest Reserve soil for improved soil nutrient bioavailability and growth characteristics in *Garcinia kola*.

Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

MATERIALS AND METHODS

Description of Study Area

The Idumuje-Ugboko Forest Reserve is situated in Aniocha North LGA, Delta State and lies within the tropical rainforest belt of southern Nigeria, a region known for its high annual rainfall, warm temperatures, and rich biodiversity. The reserve has a total area of 2582 ha, with Igbodo and Akumazi communities of Ika North East LGA and Idumuje Ugboko community in Aniocha North LGA as donor communities. Idumuje-Ugboko is located on latitude 6° 21´ 47´´N and longitude 6° 24´17´´E in the north east corner of Delta State, near the boundary with Edo State, adjoining the derived savanna ecological zone, characterized by a hot and humid climate with two distinct seasons: the wet season (April to October) and the dry season from November to March. The average temperature and precipitation of 30.1ºC and 1789 mm, respectively (FORMECU, 1999; NiMet, 2023).

The reserve had a multi-layered structure, with an emergent layer, a canopy layer, an understory, and a forest floor rich in decomposing organic matter prior to deforestation and degradation. Notable emergents included *Ceiba pentandra* (silk cotton tree) and *Terminalia superba* (African whitewood) species to provide essential habitat for birds and other wildlife, contributing to the ecological diversity of the reserve (FORMECU, 1998). Species such as *Cola nitida* (kola nut tree) and *Funtumia elastica* (rubber tree) are commonly found in the understory, contributing to the diversity of plant life.

The Forest reserve has been subject to degradation over the years, with notable dried riverbeds that have high silt and pebble content in the centre, where individuals collect stones. The anthropogenic pressures, especially logging and farming, account for over 60% degradation (Delta State Ministry of Environment, 2017), which have posed significant problems to the regeneration of *Garcinia kola*.

Soil Collection and Test

Three different soil samples at 0-30 cm depths were collected with the Dutchman hand augar in three (3) replicates as degraded forest soil from the Idumuje-Ugboko Forest Reserve in Aniocha North LGA; river soil in Asaba axis, by the Bridge Head, from the River Niger; and flood plain soil at the Oko-ogbele flood plains between Asaba and Oko-Amankon. This region of floodplain is noted with aquic soil moisture and isohyperthemic temperature regimes (Egbuchua, 2011) in Oshimili South LGA of Delta State.

Soil samples were screened with a 2mm mesh filter for pebbles, metals, and other extraneous materials. Screened samples were packaged in perforated poly pots and left under screen house conditions before analysis. Particle size distribution using the Bouyoucos hydrometer method (Day, 1965). Particle density (Bowles, 1992). Bulk density was determined by the core method. Soil pH (McLean, 1982). Total nitrogen using the modified Kjeldahl digestion and distillation method (Juo, 1979). Organic carbon using the wet oxidation method (Walkey& Black, 1945; Nelson & Summer, 1982). Exchangeable cations (Thomas, 1982). Exchangeable acidity was determined by the titration method as described by Juo (1979). Available phosphorus by the Bray No. 1 method (Brat & Kurtz, 1945).

Seed Procurement

Ripe *Garcinia kola* fruits were collected from mature trees in Ubulu-Okiti, Aniocha North LGA, Delta State. Seeds were extracted manually and sun-dried for 7days before testing for viability using the flotation method (Nwaoboshi, 1993). Selected viable seeds were then sclarified using a sewing needle originally calibrated to 0.30 and 0.50 cm to produce 2-pinholes of 0.30 cm depth at both the top and bottom at directly on opposite sides, as well as 4-pinholes of 0.50 cm deep at the middle (Schmidt, 2000) as a modification procedure. The clarified seeds were further stored in transparent, loosely tied plastic bags under screen house conditions for 48 hours to facilitate breaking of dormancy.

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Growth Media

Growth media were prepared by priming of forest reserve degraded soil (DS) samples with the River-Niger (RS) and flood plain (FP) soils at 25-75, 50-50, 40-60, 75-25 and 70-30 volume/volume in graduated brass measuring cylinder with uniform 900 g plunger to obtain primed soil types. These were allowed to properly interact through systematic mixing, wetting with 150 ml of distilled water without any compaction, and then kept under screen house conditions for 24hours before use. Soil solutions from the respective prime types were equally procured by filtration with a 2.50mm mesh size filter for 6 days.

Five (5) primed soil types comprising 25-75, 50-50, 40-60, 75-25, and 70-30 v/v for RS-DS and FP-DS, respectively, alongside the 100 v/v DS, FP, and RS, were employed in three (3) replicates for the study. *Garcinia kola* seeds were planted in poly-pots of 12 cm diameter by 30 cm depth with primed soil types filled to 25 cm under screen house conditions. One seed per poly-pot was sown to a uniform depth of 5 cm at 3 replicates per primed soil type, and watering was conducted twice weekly with the soil solutions at the rate of 0.65 litres per pot per regime.

Germination was epigeal with the hypocotyl emerging above soil level, and was taken at the 8th week after planting. Seedling height, collar diameter, leaf length, and width were taken at the 13th week after planting. Leaf surface area was computed using the linear measurement of length and width of each leaf in the seedling by Clifton and Lewandoski (2000) as adopted and applied in Adelani et al (2020).

Data Analysis

The experiment was laid out in a completely randomised design. Data collected were analysed using analysis of variance (ANOVA) and significant means separated at a 5% with the Duncan Multiple Range Test.

RESULTS

Characteristics of the Soil Used in the Study

Physical Properties

Table 1 shows a comparative analysis of the physical properties of degraded forest, river Niger, and flood plain soils used in the study. The sand content was flood plain (938.7 ± 0.41 g/kg), > degraded forest soil (901.6 ± 0.12 g/kg), and river Niger soil (879.7 ± 0.35 g/kg). The clay content was statistically different ($p < 0.05$) and lowest in the river Niger soil (10.8± 0.63 g/kg) but highest in degraded forest soil (26.3 ± 0.51 g/kg). All three soil types are classified as sandy soils (SS). The bulk density showed significant diffrences ($p < 0.05$) with flood plain soil (1.58 ± 0.63 g/cm³) > degraded forest soil (1.46 ± 0.74 g/cm³) > river Niger soil (1.38 ± 0.61 g/cm³).

There were statistical differences ($p < 0.05$) in the porosity with the highest value of 43.36 ± 0.14 % shown in the river Niger soil, > degraded forest soil (33.5 ± 0.18%) > flood plain (38.5 ± 0.16%). The moisture content was significantly different and highest in river Niger soil (32.41± 0.33%), which suggests it retains more water compared to the other soil types. Degraded forest soil has a moisture content of 26.38 ± 0.35%, and floodplain soil retains 27.18 ± 0.47% moisture.

Table 1: Physical Properties of the Study Soil Used in Priming

Properties	Soil Sources		
	Degraded Forest Reserve	River Niger	Flood Plain
Sand (g/kg)	901.6 ± 0.12[a]	879.7 ± 0.35[ab]	938.7 ± 0.41[a]
Silt (g/kg)	72.1 ± 0.66[b]	109.5 ± 0.62[a]	45.8 ± 0.54[c]
Clay (g/kg)	26.3 ± 0.51[a]	10.8 ± 0.63[bc]	15.5 ± 0.53[b]
Silt/clay ratio	2.74 ± 0.11[b]	10.13 ± 0.14[a]	2.96 ± 0.10[b]
Soil Texture	SS	SS	SS
Bulk Density (g/cm^3)	1.46 ± 0.74[b]	1.38 ± 0.61[c]	1.58 ± 0.63[a]
Porosity (%)	33.5 ± 0.18[c]	43.36 ± 0.14[a]	38.5 ± 0.16[b]

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Moisture Content (%)	26.38 ± 0.35[b]	32.41 ± 0.33[a]	27.18 ± 0.47[b]

Means ± standard errors in the same row with the same superscript are not significantly different ($p > 0.05$)

Chemical Properties

Table 2 shows a comparative analysis of the chemical properties of three soil types used - Degraded forest, river Niger, and flood plain soils. There was no significant different ($p > 0.05$) in the $pH_{(H2O)}$ of river Niger soil (6.08 ± 0.28) is slightly alkaline compared to degraded forest soil (5.45 ± 0.25) and flood plain soil (5.70 ± 0.17). Similarly, $pH_{(CaCl2)}$ was highest in the river Niger soil (5.80 ± 0.11), and was statiscally different ($p < 0.05$) form the degraded forest and floodplain soils.

River Niger soil had the highest organic carbon (4.87± 0.14%) and organic matter (8.38%) content. The organic carbon and matter was 1.44 ± 0.10 and 2.48 ± 0.34 % respectively for degraded forest soil and were significantly different ($p < 0.05$) from the river Niger and floodplain soil. The exchangeable magnesium, potassium and calcium contents of River Niger soil was significantly different ($p < 0.05$) and higher compared to the other soils. Exchangeable potassium was highest in river Niger soil (1.07± 0.01%), while flood plain soil has the least (0.24± 0.11%). TEB was significantly different ($p < 0.05$) as 16.11 ± 0.28 cmol/kg for River Niger soil while degraded forest soil (8.95 ± 0.47 cmol/kg) and flood plain soil (4.93 ± 0.42 cmol/kg).

The phosphorus was highest in river Niger soil (20.10 ± 0.34 mg/kg) and statictically different ($p < 0.05$). Flood plain soil showed the least phosphorus (4.33 mg/kg), which could limit plant growth. River Niger soil had the highest total nitrogen (0.28 ± 0.20 %) but was not significantly different ($p > 0.05$), essential for protein synthesis and overall plant health. River Niger soil with the least exchangeable acidity (0.98 ± 0.25 cmol/kg) was not significantly different from flood plain soil ($p > 0.05$), while degraded soil has the highest exchangeable capacity (1.62 ± 0.35 cmol/kg) that was significantly different ($p < 0.05$). The effective CEC differed significantly from river Niger soil (17.09 ± 0.36 cmol/kg) highest than the degraded and floodplain soils.

Table 2: Chemical Properties of the Study Soil

Properties	**Nutrient Sources**		
	Degraded Forest Reserve	**River Niger**	**Flood Plain**
$pH_{(H2O)}$	5.45 ± 0.25[a]	6.08 ± 0.28[a]	5.70 ± 0.17[a]
$pH_{(CaCl2)}$	5.12 ± 0.18[b]	5.80 ± 0.11[a]	5.30 ± 0.13[b]
Organic Carbon (%)	1.44 ± 0.10[b]	4.87 ± 0.14[a]	1.23 ± 0.22[bc]
Organic Matter (%)	2.48 ± 0.34[b]	8.38 ± 0.38[a]	2.12 ± 0.27[c]
Exchangeable Sodium (cmol/kg)	0.35 ± 0.11[a]	0.14 ± 0.16[b]	0.33 ± 0.14[a]
Exchangeable Magnesium (cmol/kg)	1.04 ± 0.12[b]	3.45 ± 0.10[a]	0.31 ± 0.13[c]
Exchangeable Potassium (cmol/kg)	0.68 ± 0.00[b]	1.07 ± 0.01[a]	0.24 ± 0.11[c]
Exchangeable Calcium (cmol/kg)	6.88 ± 0.42[b]	11.45 ± 0.25[a]	4.05 ± 0.20[c]
Total Exchangeable Base (cmol/kg)	8.95 ± 0.47[b]	16.11 ± 0.28[a]	4.93 ± 0.42[c]
Phosphorus (mg/kg)	5.53 ± 0.21[b]	20.10 ± 0.34[a]	4.33 ± 0.45[c]
Total Nitrogen (%)	0.20 ± 0.32[a]	0.28 ± 0.20[a]	0.15 ± 0.16[a]
Exchangeable Acidity (cmol/kg)	1.62 ± 0.35[a]	0.98 ± 0.25[b]	0.92 ± 0.20[b]
Effective CEC (cmol/kg)	10.57 ± 0.54[b]	17.09 ± 0.36[a]	5.85 ± 0.46[c]

Means ± standard errors in the same row with the same superscript are not significantly different ($p > 0.05$)

Soil Physical and Chemical Properties of Primed Soil Types

The physical and chemical properties of primed soils due to the reactions of river Niger soil (RS) and flood plain soil (FP) on degraded forest soil

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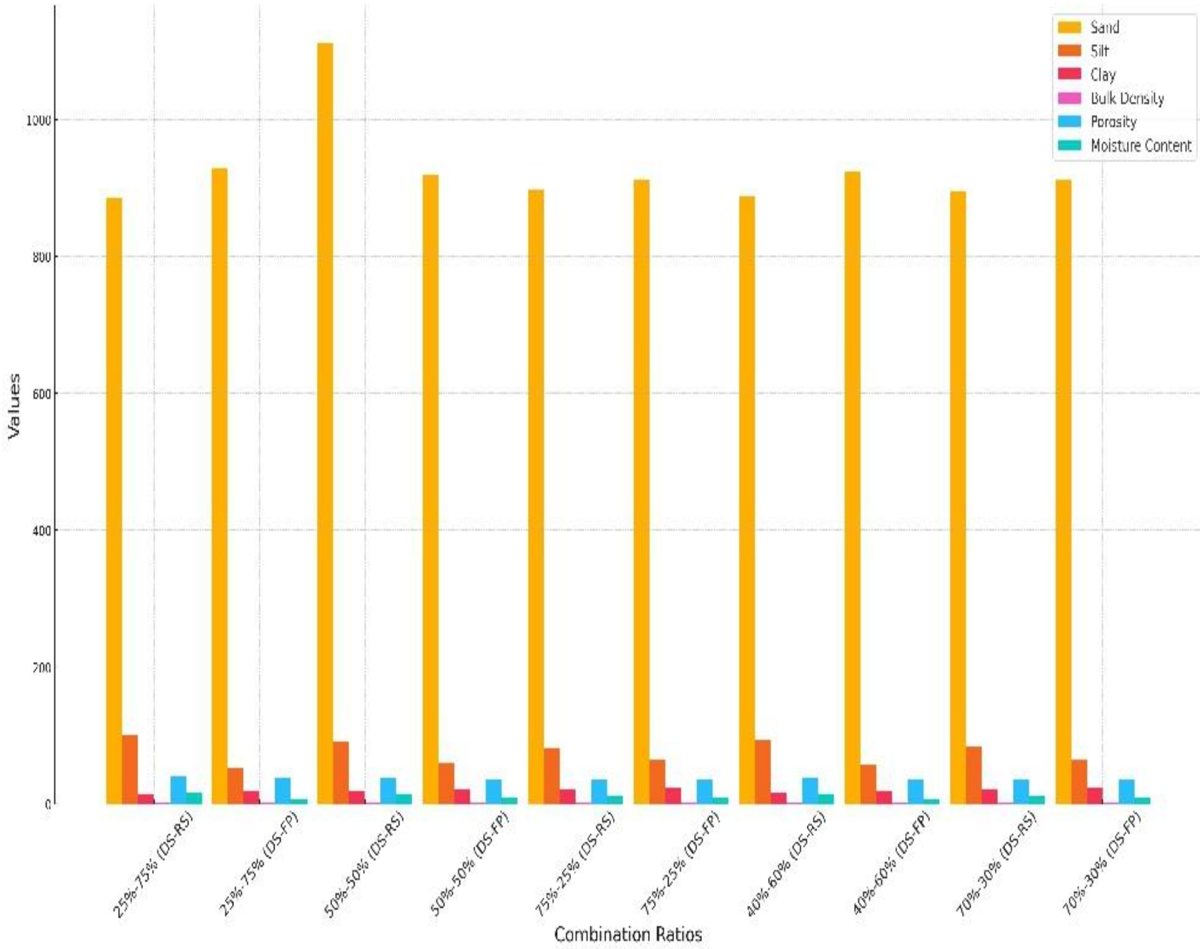
(DS) are presented in Figures 1-4. The highest particle sand was 50-50 v/v (DS-RS), particle silt (100.15 g/kg) in the 25-75 v/v (DS–RS), and particle clay (23.61 g/kg) in 75-25 v/v (DS-FP). Maximum bulk density (1.55 g/cm³) was in the 25-75 v/v (DS-FP), while the highest porosity (40.89 %) was in the 25-75 v/v (DS-RS) primed soils. The maximum moisture content (15.46 %) was shown by the 25-75 v/v (DS-RS), and the highest pH (H_2O) was in the 25-7 v/v (DS-RS).

The organic carbon was highest (4.01%) in 25-75 v/v (DS-RS), effective CEC (15.45 cmol/kg) and Mg (2.85 cmol/kg) in the 25-75 (DS-RS), Na (0.35cmol/kg) in the 70-30 (DS-FP), K (0.97 Cmol/kg) in the 25-75 v/v (DS-RS). The maximum calcium content (10.31cmol/kg) was obtained in 25-75v/v (DS-RS), phosphorus (16.45 mg/kg) in the 25-75v/v (DS-RS), and total nitrogen of 0.26% in the 25-75v/v (DS-RS). The highest exchangeable acidity (1.46 cmol/kg) was shown by 75-25v/v (DS-RS) primed soil.

Figure 1: Physical Characteristics of Primed Soil Types



Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

Figure 2: Chemical Properties of Primed Soil Types

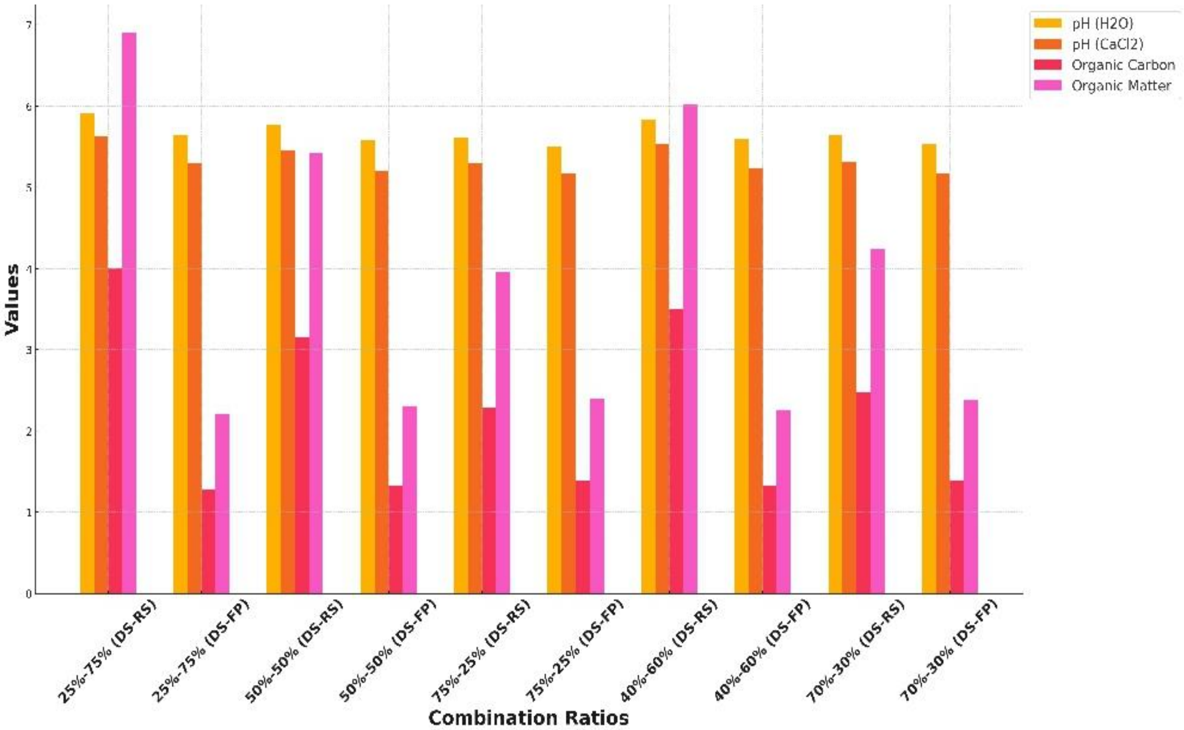
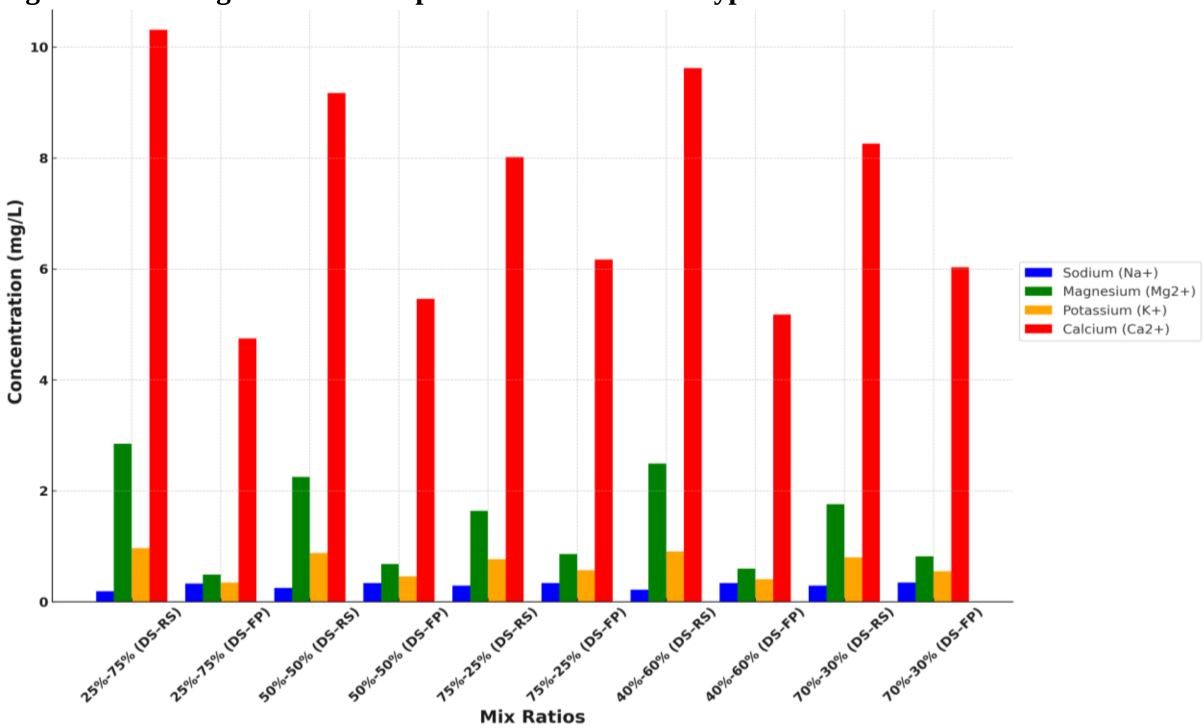
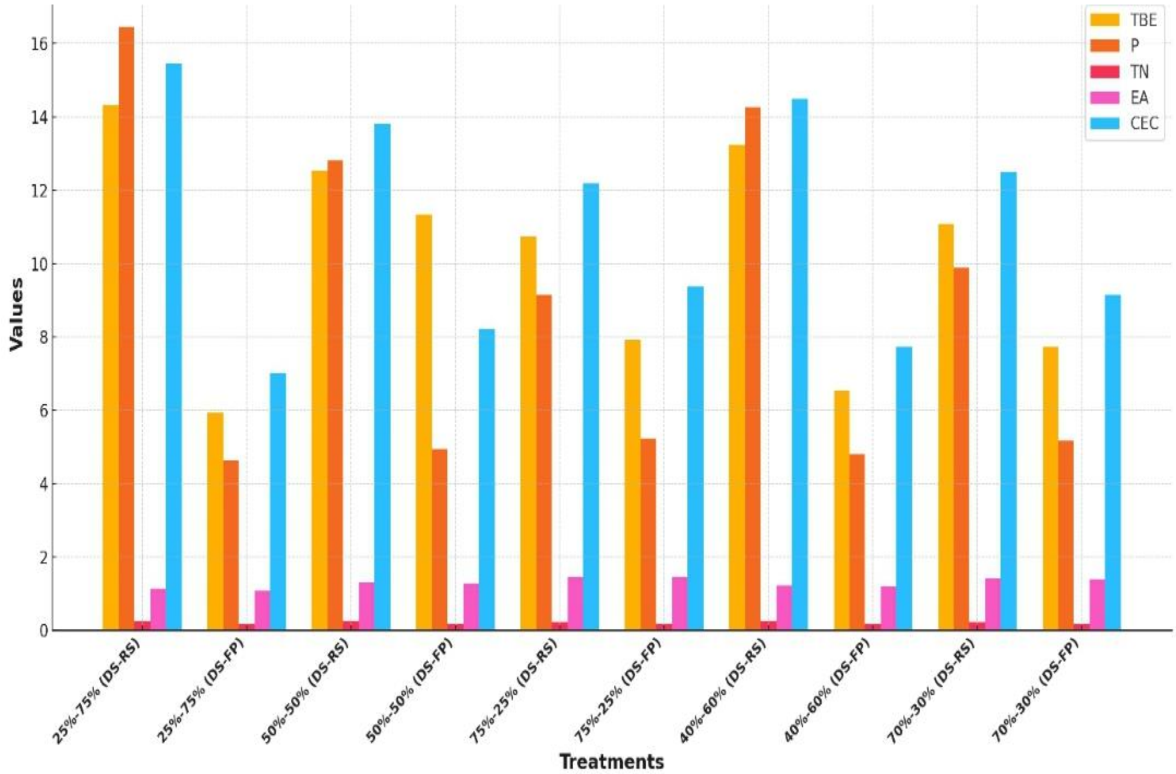


Figure 3: Exchangeable Base Properties of Primed Soil Types



Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

Figure 4: Chemical Properties of Primed Soil Types



Effect of Primed Soil Nutrients on Germination and Leaf Characteristics of *Garcinia kola* Seedlings

Table 3 shows the effect of different primed nutrients on germination and leaf characteristics. The germination rate was not significant ($p > 0.05$) between 50-50 (RS-DS), 75-25 (RS-DS) and 100 v/v DS, as well as between the germination rate of 70- 30 (RS-DS) and 100 v/v FP. The same pattern ($p>0.05$) was shown for 50-50 (FP-DS), 75-25 (FP-DS) and 70-30 v/v (FP–DS). There were no significant differences ($p > 0.05$) among the RS-DS primed soils on leaf length (Table 3). There was also no significant difference between the 50-50 v/v (RS-DS) and all the FP-DS on leaf length. But there was a significant difference between the 40-60 and 70-30 (FP-DS) and 75-25v/v (FP-DS).

The 100 (FP) and 100 v/v (RS) showed no significant difference in leaf length but differed from 100v/v (DS) with higher leaf length. The leaf width showed no significant difference among RS-DS primed nutrients ($p > 0.05$). These also did not differ significantly from the FP-DS primed soils except for 25-75v/v (FP-DS) with the largest leaf width, and 100v/v (FP), as well as 100v/v (RS) with the least leaf width. The leaf surface area was highest for 75-25 (FP-DS) > 100 (RS) > 40-60 v/v (FP-DS) with no significant differences ($p > 0.05$) between 100 FP (2.33 cm^2), 70-30 (RS-DS), and 25-75 v/v (FP-DS). There were no significant differences ($p > 0.05$) among all the RS-DS primed soils except the 70 - 30 and 40-60 v/v.

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Table 3: Effect of Primed Soil on Germination and Foliar Characteristics of *Garcinia kola* Seedlings

Recombinant Nutrient (v/v)	Germination rate (%)	Leaf length (cm)	Leaf width (cm)	Leaf surface area (cm^2)
25-75 (RS-DS)	46.67 ± 29.05[c]	2.23 ± 0.46[ab]	0.83 ± 0.24[b]	1.84 ± 0.19[c]
50-50 (RS-DS)	26.67 ± 13.33[e]	1.56 ± 0.17[b]	0.65 ± 0.10[b]	1.62 ± 0 .01[c]
75-25 (RS-DS)	33.33 ± 17.63[e]	1.43 ± 0.24[bc]	0.53 ± 0.12[bc]	1.73 ± 0.13[c]
40-60 (RS-DS)	40.00 ± 20.00[cd]	1.96 ± 0.44[a]	0.96 ± 0.31[b]	1.45 ± 0.10[d]
70- 30 (RS-DS)	20.00 ± 11.54[f]	1.43 ± 0.27[bc]	0.53 ± 0.03[bc]	2.17 ± 0.12[b]
25- 75 (FP-DS)	66.67 ± 17.63[a]	2.87 ± 0.54[a]	1.20 ± 0.32[a]	2.05 ± 0.08[b]
50-50 (FP -DS)	60.00 ± 0.00[ab]	2.20 ± 0.20[ab]	0.83 ± 0.14[b]	2.71 ± 0.49[a]
75-25 (FP - DS)	60.00 ± 11.54[ab]	1.70 ± 0.35[b]	0.53 ± 0.25[b]	2.83 ± 0.18[a]
40- 60 (FP - DS)	66.67 ± 24.03[a]	2.43 ± 0.44[a]	1.00 ± 0.36[ab]	2.47 ± 0.43[a]
70-30 (FP – DS)	60.00 ± 11.54[ab]	1.56 ± 0.27[b]	0.67 ± 0.06[b]	1.51 ± 0.11[d]
100 DS	33.33 ± 17.63[e]	1.50 ± 0.05[b]	0.96 ± 0.10[b]	1.80 ± 0.17[c]
100 FP	20.00 ± 11.54[f]	1.23 ± 0.08[c]	0.43 ± 0.08[c]	2.33 ± 0.19[b]
100 RS	6.66 ± 6.66[g]	1.20 ± 0.11[c]	0.33 ± 0.03[c]	1.67 ± 0.14[c]

Means ± standard errors in the same column with the same superscript are not significantly different ($p > 0.05$)

Effect of Primed Soil on Stem and Foliar Characteristics of *Garcinia kola* Seedlings

Table 4 shows the effect of primed soils on stem and leaf characteristics. There were no significant differences ($p > 0.05$) between the plant height of 50- 50 (RS-DS), 75-25 (RS-DS), 70-30 (RS-DS), 70-30 (FP–DS), and 100v/v DS. There were no significant differences ($p > 0.05$) between 25-75 (RS-DS), 25-75 (FP-DS), and 40- 60 v/v (FP-DS). The collar diameters showed no significant differences ($p > 0.05$) among 50- 50 (RS-DS), 40-60 (RS-DS), 50-50 (FP-DS), 75-25 (FP-DS), 70-30 (FP–DS), 100 DS, 100v/v FP. There were also no significant differences ($p > 0.05$) between 25-75 (RS-DS), 25-75 (FP-DS), and 40- 60v/v (FP-DS) primed soils. There were no significant differences ($p > 0.05$) between 25-75 (RS-DS), 50-50 (RS-DS), 75-25 (RS-DS), 70-30 (RS-DS), 100 FP, and 100v/v RS. There were also no significant differences between 25-75 (FP-DS), 70-30 (FP–DS), and 100v/v DS.

Table 4: Effect of Primed Soils on Early Growth of Characteristics of *Garcinia kola* Seedlings

Recombinant	Growth Characteristics		
Nutrient type (v/v)	Plant Height (cm)	Collar Diameter (cm)	Leaf Count
25-75 (RS-DS)	13.91 ± 2.60[b]	0.47 ± 0.08[a]	2.00 ± 0.00[e]
50- 50 (RS-DS)	8.65 ± 1.01[c]	0.34 ± 0 .05[b]	2.00 ± 0.00[e]
75-25 (RS-DS)	7.53 ± 1.16[c]	0.25 ± 0.04[cd]	2.00 ± 0.00[e]
40-60 (RS-DS)	10.63 ± 1.87[b]	0.36 ± 0.05[b]	2.67 ± 0.33[d]
70-30 (RS - DS)	7.67 ± 1.01[c]	0.23 ± 0.04[cd]	2.00 ± 0.00[e]
25-75 (FP-DS)	18.60 ± 3.46[a]	0.61 ± 0.15[a]	3.33 ± 0.33[c]
50-50 (FP -DS)	11.63 ± 0.92[b]	0.40 ± 0.05[b]	3.67 ± 033[ab]
75-25 (FP - DS)	11.93 ± 1.82[b]	0.38 ± 0.08[b]	3.67 ± 0.33[ab]
40-60 (FP - DS)	13.06 ± 1.35[b]	0.50 ± 0.07[a]	4.33 ± 0.33[a]
70-30 (FP – DS)	9.43 ± 1.24[c]	0.36 ± 0.04[b]	3.33 ± 0.33[c]
100 DS	8.67 ± 0.66[c]	0.35 ± 0.03[b]	3.33 ± 0.66[c]
100 FP	5.95 ± 0.36[cd]	0.30 ± 0.05[b]	2.33 ± 0.33[e]
100 RS	5.10 ± 0.30[cd]	0.27 ± 0.04[cd]	2.00 ± 0.00[e]

Means ± standard errors in the same column with the same superscript are not significantly different ($p > 0.05$)

Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

DISCUSSION

The influence of primed-soil properties on *Garcinia kola* seedling growth metrics provides insights as to the interaction and reaction of physical and chemical soil characteristics. The physical properties showed that flood plain soil has the highest sand content, which may have improved drainage, but with the potential of decreasing nutrient concentration by retention for probable better osmotic gradient into seed to initiate plumule and radicle emergences, particularly for recalcitrant seeds as *Garcinia kola.* This result is consistent with the findings of Haddad et al. (2021) that sandy soils generally exhibit lower water and nutrient retention capacities. The River Niger sand contains the highest silt may have enhanced fertility and moisture retention in agreement with Ogunyemi et al., (2023). The degraded forest reserve soil showed the highest porosity (43.36%), which may have enhanced aeration and root penetration as reported by Rufat *et al*. (2023) and on interaction with floodplain soil to increase nutrient sorption capacity that triggers germination (Ndiaye et al, 2022).

The 50-50 v/v (DS-RS) primed soil had the highest sand content, while silt and clay varied considerably, affecting soil texture and moisture retention, thereby possibly conferring a relative attribute of nutrient retention. Bulk density peaked in the 25-75 v/v (DS-FP) primed soil, which may have offered restricted radicle emergence and root development. But the highest porosity by the 25-75 v/v (DS-RS) primed soil nutrient may have supported better aeration and water infiltration with probable seepage of nutrient alongside. The organic carbon and moisture content were notably higher in some FP-DS primed nutrient types, which could probably have provided improved nutrient retention for seedling support as reported in Adaramoye *et al*. (2022).

The germination rate of *Garcinia kola* across primed soil types highlighted that 25-75 and 40 – 60 v/v FP-DS achieved the highest germination rates (66.67%) to indicate that flood plain soil significantly supported germination, potentially by improving soil fertility and moisture dynamics that facilitate microbial activities. This finding is in line with the observation of Egbuchua (2011) that the alluvial and colliodial residues often deposited during flooding constitute a significant fraction of organic matter (Olawale et al., 2023). This finding is particularly unique in the forest regeneration of threatened forest tree species, where the nursing and the utilisation of river sand has been the practice over the years. None of the sole sand nutrient types could stimulate germination up to 33% except the degraded forest soil, alluding that it has latent nutrients, probably from the initial forest stand, as typical of tropical forest stands. The least germination rate by sole RS (6.67%) suggests that the sole river sand nutrient type lacked essential nutrients, probably due to the capacity for moisture-retentive properties needed for the continuous bathing of the seed coat to facilitate germination. This aligns with Jimoh and Johnson (2020), who reported better results with mixed soils, which performed better than single-source soils in plantation establishment.

The 25-75 v/v FP-DS primed nutrient type produced the highest plant height along with other FP-DS combinations of 40-60 and 50-50 v/v, implicating FP and DS combinations, especially those with higher FP proportions, to have effectively supported vertical growth in *Garcinia kola* seedlings. This observation may have accounted for the same FP-DS primed nutrient types that resulted in similarly largest leaf surface areas to supply phytosynthates at the exhaustion of the seed cytoplasmic food store. Invariably, the FP-based nutrient types seem to have provided better support, probably by nutrient retention for the radicles to translate faster to roots and thereby eased the competition that may have denied the shoots' potential for leaf development. This finding concurs with Nwafor et al. (2022), who reported the capabilities of floodplain nutrient-rich soils to facilitate shoot formation due to the variegated exchangeable base ion complex that favours calcium and biomass accumulation. This ability may not be unconnected with the rich

Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

incubated larvae of sea creatures, often transported during overflow and flooding, left in the plains to hibernate and reproduce.

Longest leaf lengths were produced by the 25-75 v/v (FP-DS) primed soil type, while other FP-DS combinations also supported robust leaf length growth to justify the nutrient priming effect with the FP-based types for foliage development. This may not be unrelated to incorporated organic matter following stagnancy within the flood plains. This observation is in line with Machado et al (2022) that soils rich in variegated organic matter enhanced leaf development by providing essential nutrients.

The FP-DS primed types had the highest leaf surface area as 75-25 > 75-25 > 40-60 v/v, buttressing the possible superiority of component flood plain nutrients as optimal for leaf development of *G. kola*. Even the sole (100 v/v) flood plain soil type showed better support in leaf surface area development to reveal its sustainable nutrient release potential due to the alluvial fractions. This finding agrees with Adesina et al. (2020) that combining different soils with different structural textures enhances leaf surface area because of the possibilities in improving soil structure and nutrient dynamics from the interactions of aeration and microbial activities, which may enhance its fertility and water retention capacity.

The RS-DS and FP-DS were not different in leaf numbers, while only FP-DS notably contributed to the leaf count. This may not be unconnected with the activity of inherent nutrient types in facilitating cell division and bud production. This observation may have accounted for the performances of the FP-DS (75-25, 40-60, and 50-50 v/v) primed nutrient types on leaf count. While the highest proportion of FP-base in FP-DS produced the highest leaf count, the 70-FP base resulted in a smaller leaf count compared to the 50, 40, and 25-FP bases in the FP-DS primed types. This implies a likelihood of an optimal concentration probably induced by exchangeable base and cation exchange capacity, above which such potential to supply nutrients becomes either reduced or impaired. This concurs with Egbuchua (2011), who reported high clay content as a possible index of soil ability to support plant growth because of the presence of colloidal materials that are often adsorbed in the soil.

However, the stability and resultant primed effect of the FP-base on the degraded forest soil (DS) for increased leaf number in *Garcinia kola* appears to peak between 25-75 v/v FP. The same trend was followed in the collar diameter and plant height, respectively. Moderate FP base in the DS resulted in the highest plant height, collar diameter, and leaf count. The 25-75 (FP-DS) gave the best plant height and collar diameter, while 40-60 (FP-DS) highest leaf count. Whereas the sole FP and DS showed a lower nutrient effect on *Garcinia kola* seedlings.

Generally, the introduction of pinholes of different sizes and depths along the *G. kola* seeds may have equally contributed to solute intake to break dormancy associated with the seed testa and achieve faster germination, as well as other growth characteristics within 8 weeks compared to the 24 - 48 weeks reported in literature. This is because such holes could have acted as ducts to retain soil nutrient solutes to manage internal water and nutrient stress, often encountered in recalcitrant hard tropical fruits at exhaustion of cytoplasmic food stores. This approach may have depended on the infiltration capacity allowances as engineered by the respective primed soil structures to admit external soil nutrient solutes and thereby averting the usual heavy physiological demand that would have retarded radicle and plumule emergence.

CONCLUSION

The study revealed that primed soil types with higher FP base in the DS-FP nutrients optimised *Garcinia kola* germination and development. This demonstrated that soil structure was enhanced to facilitate other critical nutrient exchangeable base reactions in favour of foliar growth for higher net photosynthetic productivity in degraded forest soils. The study unveils an innovative application of floodplain soil as a departure from the conventional river sand in nursery amendment for

Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

dormancy breakage in *Garcinia kola* regeneration, with a significant reduction in gestation period. Thus, the FP-DS primed nutrient bases as a possible augmentation formulation for lost vegetation stand litter in sustainable forest management initiatives in the restoration of degraded tropical forest soils.

REFERENCES

Adaramoye, O., Olayinka, I. A., and Odebunmi, E. O. (2021). Study on kolaviron, a biflavonoid in *Garcinia kola*, for its antioxidant and anti-inflammatory properties. *Journal of Food Biochemistry*, 45(7), e13718.

Adebayo, A. H., Adetayo, R. I., and Olayiwola, I. (2023). Challenges in the propagation of *Garcinia kola*: Insights from recent research. *Journal of Agricultural Sciences*, 15(2), 142-155.

Adebisi, M. A., Akindele, A. J., and Akinola, O. S. (2021). Medicinal uses and ecological value of *Garcinia kola*. *Journal of Medicinal Plants Research*, 15(7), 124-132.

Adelani, D.O., Osunsina, O., and Aiyelaagbe, I.O. (2020). Effect of Nutrient sources and light intensities on seedling vigour of African Star Apple (Chrysophyllum albidum, G.Don). *Journal of Research in Forestry, Wildlife and Environment*, 12 (1), 148-155.

Adesina, F., Ogunwusi, A. A., and Adeyemo, O. (2020). Study on the taproot system of *Garcinia kola* and its drought resistance. *Nigerian Journal of Botany*, 33(1), 14-22.

Alam A.U., Ullah H., Himanshu S.K., Tisarum R., Cha-um S., and Datta A. (2023). Seed Priming Enhances Germination and Morphological, Physio-Biochemical, and Yield Traits of Cucumber under Water-Deficit Stress. *J. Soil Sci. Plant Nutr*. 23,3961–3978. doi: 10.1007/s42729-023-01314-3.

Anegbeh, P.O., Iruka, C., and Nkiruka, C. (2008). Enhancing germination of Bitter kola (*Garcinia Kola*): Prospects for Agroforestry farmers in Niger-Delta. World Agroforestry Centre (ICRAF). International Institute for Tropical Agriculture (IITA) High Rainforest Station, Onne, River State. Nigeria,7pp.

Babin, D., Deubel, A., Jacquiod, S., Sørensen, S.J., Geistlinger, J., Grosch, R., and Smalla, K. (2019). Impact of long-term agricultural management practices on soil prokaryotic communities. *Soil Biol. Biochem.*, 129, 17–28.

Bagarinao NC, King J, Leong SY, Agyei D, Sutton K, and Oey I. (2024). Effect of Germination on Seed Protein Quality and Secondary Metabolites and Potential Modulation by Pulsed Electric Field Treatment. *Foods*, 13(11), 1598. doi: 10.3390/foods13111598.

Ballinger, A., and Lake, P. S. (2006). Energy and nutrient fluxes from rivers and streams into terrestrial food webs. *Marine and Freshwater Research*, 57(1), 15-28. https://doi.org/10.1071/MF05154

Bradford MA, Veen GFC, Bonis A, Bradford EM, Classen AT, Cornelissen JHC, Crowther TW, De Long JR, Freschet GT, Kardol P, Manrubia-Freixa M, Maynard DS, Newman GS, Logtestijn RSP, Viketoft M, Wardle DA, Wieder WR, Wood SA, and van der Putten WH. (2017). A test of the hierarchical model of litter decomposition. *Nat Ecol Evol*., 1(12),1836-1845. doi: 10.1038/s41559-017-0367-4

Bray, R.H., and Kurtz, C.T. (1945). Determination of total organic and available forms of phosphorus in soils. *Soil Science*, 59, 39-45

Bruijnzeel LA (1991). Nutrient input-output budgets of tropical forest ecosystems: a review. *Journal of Tropical Ecology*, 7,1-24.

Camenzind, Tessa, Mason-Jones, Kyle, Mansour, India Rillig, Matthias Lehmann, Johannes. (2023). Formation of necromass-derived soil organic carbon determined by microbial death

Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

pathways. *Nature Geoscience*, 16, 1-8. 10.1038/s41561-022-01100-3.

Chapin, S., Matson, P.A., Mooney, H.A., and Chapin, M.C. (2002). Principles of Terrestrial Ecosystem Ecology. Springer: New York.

Cowie AL, Penman TD, and Gorissen L (2011). Towards sustainable land management in the drylands: scientific connections in monitoring and assessing dryland degradation, climate change and biodiversity. *Land Degrad Dev*, 260,248–260. https://doi.org/10.1002/ldr.1086

Day, F. R. (1965). Particle fractionation and particle size analysis. In C.A. Black (ed). Methods of Soil Analysis. American Society of Agronomy. Madison, Wisconsin, USA, pp 545-566.

Delta State Ministry of Environment (2017). Report of forest reserve refragmentation for Donor Communities and special projects. Department of Environmental Conservation, Ministry of Environment, Asaba, 45pp.

Dogara, A.M., Hamad, S.W., Hama, H.A., Bradosty, S.W., Kayfi, S., Al-Rawi S.S., and Lema, A.A. (2022). Biological evaluation of *Garcinia kola* Heckel. *Advances in Pharmacological and Pharmaceutical Sciences*. 22,1-15.

Egbuchua, C.N. (2011). A pedological characterization of soils of River Niger alluvial complex of Nigeria. *Nig Journal of soil and Environmental Research*, 9, 65-70.

Egwunatum A. E. Dolor D. E., and Umeh P. C. (2020)a. Evaluation of forest litter mineralization capacity on the growth of Irvingia gabonensis in Ogwashi-Uku Forest Reserve, Delta State, Nigeria. *Journal of Horticulture and Forestry*. 12(2), 49-56

Egwunatum A. E., I. K. Okore, D. E. Dolor, and N. V. Orji (2020)b. A preliminary evaluation of bamboo tree effect on selected properties of coal spoil contaminated soils of a humid area of southern Nigeria. *International Journal of Agriculture and Biological Sciences*. 4(4), 76-83.

Ewetan, I. O., (2021). Soil fertility management in degraded forest soils for Garcinia kola cultivation. *Nigerian Journal of Agriculture, Food and Environment*, 17(1), 10-20.

FAO (2020). State of the World's Land and Water Resources for Food and Agriculture (SOLAW) 2021. Food and Agriculture Organization of the United Nations.

FORMECU (1998). Assessment of vegetation and land-use changes in Nigeria, between 1976/78 and 1993/95; unpublished report prepared by Geomatics International Inc., Beak International Incoporated, and Unilag Consult, 221p.

FORMECU (1999). Forest resources study. Revised Forest Management Plan for Delta State.122p

Fujii K., Shibata M., Kitajima K., Ichie T., Kitayama K., and Turner B.L. (2018). Plant–soil interactions maintain biodiversity and functions of tropical forest ecosystems. *Ecological Research*., 33 (1), 149-160.

Gupta, G.S. (2019). Land degradation and challenges of food security. *Review of European studies*, 11(1), 63-72.

Haddad, S. A., Mukhtar, A. M., and Ranjha, M. M. A. (2021). Soil texture and its impact on crop growth: A review. *Agronomy*, 11(11), 2252.

Irfan, S. and Alatawi, A. (2019). Aquatic Ecosystem and Biodiversity: A Review. *Open Journal of Ecology*, 9, 1-13. doi: 10.4236/oje.2019.91001.

Lal, R., Stewart, B. A., and Uphoff, N. (2020). Climate-Smart Agriculture: Enhancing Resilient Agricultural Systems, Landscapes, and Livelihoods. Springer Nature.

Li, X., Zhang, Y., Wang, J., and Huang, C. (2021). Effects of soil amendments on soil quality and plant growth in degraded forest ecosystems. *Ecological Engineering*, 169, 106-116.

Luo, W., Zhang, X., and Liu, Y. (2021). Microbial dynamics and nutrient cycling in soils amended with organic compost and manure. *Ecological Engineering*, 158, 106045

Lyu, D., Liu, Q., Xie, T. and Yang, Y. (2023). Impacts of different types of Vegetation Restoration on the Physicochemical properties of Sandy Soil. *Forests*. 14, 1740. https://doi.org/10.3390/f14091740.

Machado, Ana, Dalila Serpa, Ana Karolina Santos, Ana Paula Gomes, Jan Jacob Keizer, Bruna and R.F. Oliveira, (2022). Effects of different amendments on the quality of burnt eucalypt forest soils – A strategy for ecosystem rehabilitation. *Journal of Environmental Management*, 320, 115766, https://doi.org/10.1016/j.jenvman.2022.115766.

Marthandan V., Geetha R., Kumutha K., Renganathan V.G., Karthikeyan A., and Ramalingam J. (2020). Seed Priming: A Feasible Strategy to Enhance Drought Tolerance in Crop Plants. *Int. J. Mol. Sci.* 21, 8258. doi: 10.3390/ijms21218258.

McLean, E.O. (1982). Soil pH and Lime requirement. *In* Page, A.L., Millers, R.H. and Keeney, D.R. (eds). Methods of Soil Analysis. Part 2-Chemical and Microbiological Properties (2nd Ed), *Agronomy* 9, 199-224.

Ndiaye, M., Thiam, A., and Samb, C.O. (2022). Study of the germination and growth of seeds of *Jatropha curcas* L. depending on the duration and mode of storage, *Journal of Applied Biosciences* 179,18745–18761.

Nelson, M.J., and Sommers, L.E. (1982). Total carbon, organic carbon and organic matter. In: Page, L.A., Miller, R.H. and Keeney, D.R. (eds), Methods of Soil Analysis, pp. 539-579. Part 2. Chemical and Microbiological Methods (2nd ed). American Society of Agronomy. Madison, W.I.

Nwafor, C. A., Nwafor, A. M., and Okeke, B. C. (2022). Nutrient improvement and survival rates of seedlings in recombinant sand-amended soils. *Journal of Soil Science and Environmental Management*, 13(5), 45-52.

Oboho, E.G., and Urughu, J.A. (2010). Effects of pregermination treatments on the germination and early growth of *Garcinia kola* (Heckel). *African Journal of General Agriculture*, 6, 167-181.

Olawale, M. O., Ojo, J. A., and Olatunji, O. (2023). Use of recombinant sand for improved water retention in soil supporting the growth of *Garcinia kola*. *Environmental Sustainability*, 6(2), 235-243.

Raven, P.H., Ray, F.E., and Susan, E. (2005). Biology of plants, 7th edition, New York. WH Freeman and Company publishers. 504-508pp.

Schmidt, L. H. (2000). Guide to handling of tropical and subtropical forest seed. Danida Forest Seed Centre. Humlebaeck, Denmark.

Sileshi, G.W., Mafongoya, P.L., and Nath, A.J. (2020). Agroforestry Systems for Improving Nutrient Recycling and Soil Fertility on Degraded Lands. In: Dagar, J.C., Gupta, S.R., Teketay, D. (eds) Agroforestry for Degraded Landscapes. Springer, Singapore. https://doi.org/10.1007/978-981-15-4136-0_8

Stevens, C.J., (2019). Nitrogen in the environment. *Science*, 363, 578–580.

Thomas, G.W. (1982). Exchangeable cations. In Page, A.I., Miller, R.H. and Keeney, D.R. (eds). Methods of soil analysis. Part 2. Agro. 9. Madison WI. 159-165.

Yang, T., Lupwayi, N., Marc, S. A., Siddique, K. H. M. and Bainard, L. D. (2021). Anthropogenic drivers of soil microbial communities and impacts on soil biological functions in agroecosystems. *Global Ecology and Conservation*, 27, Article e 01521. https://doi.org/10.1016/j.gecco.2021.e01521

Article DOI: https://doi.org/10.37284/eajfa.8.1.3309

Zhang, Y. and Wang, H. (2021). Soil organic carbon dynamics under different agricultural practices: A review. *Agricultural Systems*, 185, 102930.