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Effects of carbide waste-amended soil on germination and early seedling growth of *Irvingia wombolu* var. *vermoesen* (Bush mango)

Oghenekevwe Abigail Ohwo[1+]
Kesiena Tina Ogeh[2]
Patience Ndidi Emilimor[3]
Ehimwenma Odiase[4]
Ighoyivwi Onakpoma[5]
Dickens Efemena Dolor[6]

[1,2,3,6]*Department of Forestry and Wildlife, Delta State University, Abraka, Nigeria.*
[1]*Email:* oghenekevweabigail@gmail.com
[2]*Email:* ktina.ogeh@delsu.edu.ng
[3]*Email:* pemilimor.nd@delsu.edu.ng
[6]*Email:* dedolor@delsu.edu.ng
[4]*Business School, University of Wolverhampton, Wolverhampton, England, United Kingdom.*
[4]*Email:* odiwem@gmail.com
[5]*Department of Wood Science and Engineering, Oregon State University, Corvallis, OR 97331, United States.*
[5]*Email:* ighokpoma@yahoo.com


(+ Corresponding author)

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ABSTRACT

Carbide waste perceived as harmful to the environment is used in soil liming to minimize high soil acidity, which is responsible for low crop productivity. Irvingia wombulu remains a high-value and widely used tropical African tree species. The germination and seedling growth of Irvingia wombulu in soils amended with carbide waste were assessed. Polypots measuring 30 cm in height and 24 cm in diameter, filled with 10 kg of soil mixed with carbide waste powder at rates of 0, 35.2, 70.4, 105.6, and 140.8 g kg-1, were used in germination trials of 450 I. wombulu seeds, arranged in a completely randomized design. Growth data, including plant height, stem diameter, leaf number, and germination percentage, were recorded over 16 weeks. The ANOVA analysis showed significant differences, with means separated using standard error of the means (SEM). Germination percentage, leaf area, and stem girth were unaffected ($p > 0.05$) by carbide application. Seedling height ranged from 32 cm in the control to 37.8 cm in soils amended with 140.8 g kg-1 carbide. The study suggests that carbide waste inclusion is not detrimental to I. wombulu germination. Carbide waste is recommended as an appropriate nursery amendment material at approximately 40.8 g kg-1 for improved performance of I. wombulu seedlings in nurseries.

Contribution/Originality: Polluted soils impact seedling growth for afforestation. The growth of Irvingia wombolu seeds was studied in soils amended with carbide waste. The species survived across different carbide waste levels, indicating potential for large-scale cultivation that benefits both economic development and environmental sustainability.

1. INTRODUCTION

Irvingia wombulu (bush mango) is a highly valued tropical African tree species, recognized as a priority for conservation. Its products are commercially significant in Nigeria, Cameroon, and Côte d'Ivoire. The annual demand for *I. wombulu* fruits (Ogbono) in Nigeria is approximately 80,000 tonnes, providing a sustainable income for rural communities [1]. Rural households harvest the species both for subsistence during given seasons when other income sources are low [2, 3]. Many rural households in these regions depend on non-timber forest products (NTFPs) for their food, medicinal, and cultural needs [4].

Like most NTPFs, I. gabonensis and I. wombulu are natural forest components, usually not cultivated, but increasingly managed intensively for domestication purposes [5]. This pursuit is connected to the significant economic potential as a multipurpose resource in the West and Central Africa regions [6].

Chukwudebelu et al. [7] put the average daily production of carbide sludge by over 25,000 automotive technicians (Panel Beaters) scattered all over Nigeria at 750,000 kg. The sludge is dumped indiscriminately, causing serious health and environmental issues. According to Büll et al. [8], applying industrial residue in agriculture to supply essential nutrients and aid soil liming is a promising alternative for soil fertilization and liming management. Calcium carbide waste, also known as carbide lime or calcium hydroxide, produced during acetylene gas manufacturing for welding and industrial purposes, is often disposed of improperly across Nigeria. This waste is a valuable source of liming material for acidic soils.

According to Carbide Industries LLC [9], farmers utilize carbide lime to neutralize the effects of acid rain and acidic water runoff. Lime is an affordable aid for maintaining fertility and land health, preserving soil chemical conditions, enhancing drainage, increasing aeration, and stabilizing soil structure.

Although incinerated ash and carbide lime deposited in landfills are disruptive and environmentally harmful, vegetation can be introduced to prevent water and wind erosion. This approach may also mitigate negative environmental impacts and enhance the aesthetic appeal of industrial landscapes [10].

Quaggio [11] and Passos et al. [12] identified high soil acidity as a primary cause of low crop productivity. They emphasized the importance of using soil correctives, such as liming, for sustainable agriculture. Optimal plant nutrition depends not only on soil nutrient levels but also on the soil's ability to supply nutrients and the plant's capacity to utilize them efficiently [13]. Liming is both an effective and dominant practice to improvement in crop yields by raising soil pH and reducing acid-related constraints [14, 15]. Accordingly, Moreira and Fageria [16] obtained a quadratic increase in Alfalfa dry matter with increasing lime application, maximized at a lime rate of 8.0 Mg ha^{-1}, with a positive linear correlation between root and nodule dry matter with lime rates. However, the use of alkaline by-products introduces the risk of additional metals into the soil that may impact plant growth in the future if the soil pH migrates outside the optimal 7.0-8.4 boundary conditions [17].

In Nigeria, poor technological advancement has consistently produced excessive waste. This study aims to assess the impact of carbide waste on the growth of Irvingia wombolu seeds.

2. METHODOLOGY

The experiment was conducted at the Teaching and Research Farm of the Department of Forestry and Wildlife, Delta State University, Asaba Campus, located at 06°14′N and 06°49′E, Delta State. The environmental conditions included a temperature of 28.6°C, rainfall of 1,505mm, relative humidity of 69–80%, and sunshine of 4.8 hours [18].

2.1. Experimental Samples Collection and Preparation and Design

Four hundred and fifty mature *Irvingia wombulu* fruits were obtained from fruits collectors in Asaba, de-pulped and sundried for three days prior to sowing.

The carbide waste sludge was obtained from auto mechanical workshops located in Asaba, sundried and ground into powder using a mortar and pestle.

The top soil used in the experiment (0–20 cm depth) was amassed from the Departments farmland. The soil was air-dried and passed through a 2 mm sieve to homogenize it.

Two seeds each of *Irvingia wombulu* were sown in 30 cm height by 24 cm in diameter polypots filled with 10 kg of soil mixed with carbide waste powder, incorporated 30 days before planting, at rates of 0, 35.2, 70.4, 105.6, and 140. 8 g kg^{-1} treatments respectively and arranged in completely randomized design. The polypots were watered to field capacity daily. Germination percentage, plant height (cm), leaves number, stem girth and leaf area (cm^2) were assessed weekly.

2.2. Data Analysis

The obtained data were analyzed with ANOVA, and significant treatment means were separated using the standard error of means (SEM). Percentage data were arcsine-transformed prior to analysis. Sprouting percentage was calculated. The criterion for seed germination was visible protrusion of seedlings' cotyledons and hypocotyls on the soil surface up to 0.50 cm. Leaf number was determined by direct count. Plant height (cm) was measured with a measuring tape. Leaf area was derived from the length and breadth of the longest leaf per plant subplot. Stem diameter (collar girth in cm) was measured with a calibrated veneer caliper.

Soil samples were collected with a soil auger at random from the experimental site at a depth of 0-15 cm. The samples were air-dried, crushed, and sieved through a 2 mm mesh. They were then analyzed in the laboratory. Soil pH was determined in water using Bechman's pH meter, with a soil-to-water ratio of 1:2.5 [19]. The hydrometer method ascertained Soil particle size distribution according to Bouyoucos [20], organic carbon content by the Walkey-Black method [21], and total nitrogen content by the micro-Kjeldahl method [22]. Exchangeable bases (Na, K, Ca, and Mg) were determined after leaching with ammonium acetate solution, while exchangeable Ca and Mg concentrations were taken from the spectrometer readings [23]. Available P was obtained by the Bray I method [24].

3. RESULTS

3.1. Soil Analysis

The result of physical and chemical pre-calcium carbide waste soil treatment is shown in Table 1. The soil is best described as sandy loam with soil pH of 6.24 and an organic carbon (%) of 0.91.

Table 1. Pre-soil treatment soil analysis.

Soil characteristics	Values
Particle size distribution (%)	
Sand	74
Silt	12
Clay Silt: Clay ratio	14 0.86
Textural class	Sandy loam
Soil pH (H_2O)	6.24
Organic carbon (%)	0.91
Organic matter (%)	0.53
Total N (%)	0.05
Carbon: Nitrogen	18.2
Available P (ppm)	38.3
Exchangeable cations ($cmolkg^{-1}$)	
Ca	1.33
Mg	1.73
K	1.33
Na	0.43
CEC ($cmolkg^{-1}$)	12.57
% Base saturation	24.2

Source: Data analysis (2023).

3.2. Germination Parameters Assessment

Carbide waste soil pretreatments did not influenced germination percentage of *Irvingia wombulu* seedlings (Table 2). In general, seedlings did not germinate in week 1. There was no significant difference (P>0.05) in the germination rate of *I. wonbulu* from week 1-16. Plant height of *I. wombolu* seedlings shows no significant difference (P>0.05) from week 1-9 under different levels of calcium carbide soil pretreatment (Table 3), although there was a gradual increase in height over time. Plant heights significantly improved (P<0.05) from weeks 10 and 11 and weeks 13-16, with the 140.8g and 105.6g carbide-treated soils recorded better performance than other treatments and control. Generally, the treated soils enhanced growth characteristics more effectively than the control.

There was no significant difference (P>0.05) in *Irvingia* seedlings' stem girth from week 1 to 16 (Table 4).

The effect of carbide waste soil pretreatment on leaf number indicated in Table 5, shows no noticeable effect of treatment (P>0.05) from Week 1 to 11. Thereafter, leaf numbers increase gradually over time. Significant effect (P<0.05) in leaf numbers was observed from week 12, with 35.2gm, 70.4gm and 140.8gm carbide amended soils recording higher leaf numbers than 105.6gm and control at weeks 12 and 13. At weeks 14 and 15, control was not different from the 70.4 g and 105.6 g carbide-amended soil. Overall, 140.8g performed best relative to other treatments and control.

No significant effect exists in *I. wombolu* seedlings' leaf area in carbide waste soil pretreatment from week 1 to week 16 (P>0.05) as indicated in Table 6.

Table 2. Effect of carbide waste soil pretreatment on *Irvingia* germination percentage.

Carbide waste content (g)	Days after sowing seeds													
	Three	Four	Five	Six	Seven	Eight	Nine	Ten	Eleven	Twelve	Thirteen	Fourteen	Fifteen	Sixteen
0	0.81	14.82	26.61	38.95	38.95	38.95	38.95	38.95	38.95	38.95	38.95	38.95	38.95	38.95
35.2	9.62	17.72	27.10	30.05	30.05	31.71	31.71	31.71	31.71	31.71	31.71	31.71	31.71	31.71
70.4	0.81	13.32	29.88	33.05	33.05	34.50	34.50	34.50	34.50	34.50	36.16	36.16	36.16	36.16
105.6	5.22	16.06	21.78	26.19	29.35	29.35	29.35	29.35	29.35	29.35	29.35	29.35	29.35	29.35
140.8	5.22	24.53	27.86	31.03	31.03	32.53	32.53	32.53	32.53	32.53	32.53	32.53	32.53	32.53
S.E.M (0.05)	>	>	>	>	>	>	>	>	>	>	>	>	>	>

Note: > = not significant.

Table 3. Effect of carbide waste soil pretreatment on *Irvingia* plant height (cm).

Soil pretreatment	Three	Four	Five	Six	Seven	Eight	Nine	Ten	Eleven	Twelve	Thirteen	Fourteen	Fifteen	Sixteen
0	0.00	2.81	7.85	13.67	17.95	22.90	25.16	26.54	27.93	29.09	30.09	30.84	31.63	32.00
35.2	0.00	7.16	13.29	18.59	22.64	25.13	26.84	29.17	31.65	32.46	33.10	34.88	35.28	35.46
70.4	0.00	3.50	11.12	15.39	18.08	20.00	21.12	23.24	25.36	26.13	27.16	28.40	28.65	29.19
105.6	0.00	7.80	12.96	15.60	19.85	24.60	26.88	29.56	32.24	33.09	34.61	35.66	35.93	36.69
140.8	0.00	8.20	16.15	19.02	24.95	27.09	28.86	31.00	33.17	33.65	35.51	36.57	35.81	37.83
S.E.M 0.05	>	>	>	>	>	>	>	1.69	1.73	>	1.69	1.81	1.81	1.79

Note: > = not significant.

Table 4. Effect of carbide waste soil pretreatment on *Irvingia* stem girth (cm).

Soil pretreatment	Three	Four	Five	Six	Seven	Eight	Nine	Ten	Eleven	Twelve	Thirteen	Fourteen	Fifteen	Sixteen
0	0.00	0.00	0.29	0.42	0.44	0.44	0.46	0.50	0.53	0.54	0.59	0.61	0.61	0.62
35.2	0.00	0.00	0.33	0.39	0.43	0.43	0.45	0.45	0.50	0.52	0.57	0.57	0.57	0.58
70.4	0.00	0.00	0.39	0.39	0.41	0.42	0.44	0.45	0.46	0.51	0.54	0.55	0.55	0.56
105.6	0.00	0.00	0.30	0.37	0.40	0.41	0.41	0.42	0.45	0.49	0.52	0.53	0.54	0.54
140.8	0.00	0.00	0.33	0.39	0.41	0.42	0.43	0.44	0.48	0.51	0.53	0.54	0.56	0.57
S.E.M 0.05	>	>	>	>	>	>	>	>	>	>	>	>	>	>

Note: > = not significant.

Table 5. Effect of carbide waste soil pretreatment on Irvingia leaf number.

Soil pretreatment	Three	Four	Five	Six	Seven	Eight	Nine	Ten	Eleven	Twelve	Thirteen	Fourteen	Fifteen	Sixteen
0	0.00	0.88	2.65	3.58	4.92	5.79	6.54	6.96	7.35	7.73	8.00	10.00	10.56	11.31
35.2	0.00	3.25	4.00	4.75	6.22	7.54	8.25	8.90	9.79	10.06	10.06	11.75	12.95	13.94
70.4	0.00	1.00	3.37	3.54	5.42	7.17	7.88	8.22	8.71	8.98	8.98	9.27	10.61	11.29
105.6	0.00	2.12	3.25	4.12	5.08	5.79	6.66	7.22	7.83	7.99	8.04	9.34	11.79	12.73
140.8	0.00	2.25	3.50	4.88	6.25	7.16	7.63	8.25	9.42	9.88	10.50	11.75	14.93	16.31
S.E.M 0.05	>	>	>	>	>	>	>	>	>	0.59	0.63	0.67	0.86	1.06

Note: > = not significant.

Table 6. Effect of carbide waste soil pretreatment on *Irvingia* leaf area (cm^{-2}).

Soil pretreatment	Three	Four	Five	Six	Seven	Eight	Nine	Ten	Eleven	Twelve	Thirteen	Fourteen	Fifteen	Sixteen
0	0.00	5.56	33.86	49.40	55.09	60.44	66.50	77.29	77.56	80.82	99.16	103.05	105.89	109.53
35.2	0.00	13.09	38.31	55.10	67.51	69.39	70.43	74.57	82.23	84.55	88.23	96.75	102.83	107.85
70.4	0.00	5.62	38.58	49.14	57.52	64.55	68.80	74.33	83.26	86.60	93.16	103.47	108.30	113.75
105.6	0.00	26.11	46.75	53.68	63.44	76.45	83.99	90.72	96.62	124.17	149.95	159.32	166.69	170.54
140.8	0.00	21.34	48.86	66.62	69.74	73.94	77.88	84.08	87.60	93.79	100.34	105.41	109.43	113.02
S.E.M 0.05	>	>	>	>	>	>	>	>	>	>	>	>	>	>

Note: > = not significant.

4. DISCUSSION

4.1. Soil Analysis

The soil analysis confirms the findings of Ibode et al. [25], who described the experimental plot's soil as sandy loam with 78.50% sand, 8.50% silt, and 3.00% clay. The nitrogen, potassium, and phosphorus levels before treatment support Kilasho et al. [26]'s report, which observed higher nitrogen and lower potassium and phosphorus levels in the topsoil of the study site prior to treatment application.

4.2. Germination Parameters Assessment

The germination trial results align with findings by Okafor [27] and Nya et al. [28], who reported that *Irvingia wombolu* seeds take over 14 days to germinate. The minimal impact of carbide waste soil pretreatment on germination percentage suggests that carbide did not interfere with or limit the existing soil conditions, such as warmth, air, and water pore spaces, which are indicated by the favorable silt-to-clay ratio. This ratio may have created internal tension due to the clay's water-tight nature, generating the warmth necessary for hypogeal germination. This observation supports Hoyle et al. [29], who stated that seed germination is regulated by seed dormancy and environmental factors, and Follmer et al. [30], who found that soil nutrients and pH do not significantly influence germination. However, these results contrast with reports that calcium carbide releases acetylene and ethylene, which are involved in seed growth and development, from germination to organ senescence [31, 32].

The enhanced shoot growth, indicated by increased plant height and leaf number following carbide waste application, aligns with findings by Brown and Jennings [15] and Teshale et al. [33]. In earlier research, Brown and Jennings [15] observed that calcium hydroxide pre-plant soil treatment stimulated apple growth over three seasons. Similarly, Teshale et al. [33] reported that lime application significantly increased hybrid Arabica coffee seedling growth and improved soil nutrient availability. Liming also helps mitigate aluminum toxicity, enhances calcium and phosphorus availability, and reduces phosphorus fixation [34]. These results are consistent with Passos et al. [12], who linked soil liming to improved plant growth by increasing plants' ability to absorb water and nutrients. This is achieved through promoting soil micro-organism proliferation and encouraging the development of a more extensive root system.

The positive response of *I. wombolu* plant height to carbide waste amendment may have been a result of the high-water osmotic potential created by the carbide chemical components. This probably would have accounted for a profuse movement of held water from the favorable silt: clay ratio to increase available soil solutes for the remarkable height. This reason clearly explains the difference between the heights at the various level's amendments and the control. These results agree with Abeles et al. [31] and Arshad and Frankenberger [32].

However, the lowest plant height was obtained with the 70.4 g, compared to the other levels of amendments, due to insufficient calcium available to enhance plant growth. This agrees with Aulakh et al. [35] who reported that calcium carbide may serve as a supplementary source of calcium, which is needed for growth and cell wall formation in plants. It also agrees with the findings of El Habbasha and Faten [36] that calcium plays an important role in the stability of the cell membrane and cell integrity, is important for cell growth, cell division, cell wall formation and it is associated with the transport of nitrogen and interaction with potassium and phosphorus. Calcium is used in soil amendment to correct soil acidity [15].

Plant height response to carbide waste observed may also have been because of nitrogen availability in the soil needed by seedlings due to Carbide lime inclusion. Arshad and Frankenberger [32] stated that researchers have used calcium carbide as a nitrification inhibitor in soil and have reported substantial improvement in nitrogen economy.

Irvingia wombolu leaves responded positively to carbide waste contamination, with all treatments outperforming the control. This suggests carbide waste may not be harmful to leaf numbers. The low leaf count at 70.4 g is likely due to reduced activity of ammonia-oxidizing enzymes involved in nitrification. These findings align with studies by Abeles et al. [31] and Aulakh et al. [35], indicating minimal adverse effects from carbide waste [35].

Stem girth and leaf area showed no response of Irvingia to carbide waste inclusion, possibly due to efficient internal nutrient transfer, which is more effective along the stem than radially. This could explain the significant height improvement observed in treatments amended with carbide. Proper nutrient transfer enhances growth responses in plants.

5. CONCLUSION AND RECOMMENDATION

The study indicated that soil amendment with carbide waste positively affected the growth of Irvingia wombolu seedlings. Incorporating carbide waste into the soil during the nursery stage can improve the propagation of Irvingia wombolu effectively.

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Institutional Review Board Statement: This study was approved by the Institutional Review Board of [Department of Forestry and Wildlife, Delta State University, Abraka, Nigeria], under protocol number [IRB No. FAWDSU/160623/0025], dated June 16, 2023. Informed verbal consent was obtained from all participants, and all data were anonymized to protect participant confidentiality.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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