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EFFECTS OF CARBIDE ON THE MICROBIOLOGICAL AND PHYSICOCHEMICAL PROPERTIES OF SOIL

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ABSTRACT

Calcium carbide is widely used in fruit ripening but its waste poses environmental risks when it enters agricultural soils. This study investigated the effects of different concentrations of calcium carbide (0%, 0.5%, 1.0%, 2.0%, and 5.0% w/w) on the physicochemical and microbiological properties of loamy agricultural soil from the Owerri, Imo State. Soil samples were incubated for 30 days under controlled laboratory conditions. Results showed a significant dose-dependent increase in soil pH (from 6.45 to 8.67) and electrical conductivity, alongside increases in available phosphorus and exchangeable calcium. However, organic carbon, total nitrogen, and exchangeable potassium declined. Total heterotrophic bacteria, fungi, and actinomycetes counts decreased drastically, with near-complete suppression of fungi at 5.0% carbide. These findings indicate that calcium carbide alters soil chemistry and exerts strong antimicrobial effects, potentially impairing soil fertility and microbial ecosystem functions. Strict regulation of carbide waste disposal and adoption of safer alternatives are recommended.

Keywords: Calcium carbide, soil pollution, physicochemical properties, soil microbiology, Niger Delta, microbial inhibition

Introduction

Soil is a dynamic natural system composed of mineral particles, organic matter, water, and living organisms. It plays a critical role in supporting plant growth, nutrient cycling, and ecosystem sustainability. However, increasing anthropogenic activities have led to widespread soil pollution, particularly in developing regions where industrial and mechanical wastes are often improperly managed (Kolwzan *et al.,* 2006).

In Nigeria, common sources of soil contamination include wastes from automobile workshops, such as spent engine oil, battery residues, and calcium carbide waste. Calcium carbide (CaC_2) is widely used for the production of acetylene gas in welding operations. Its by-products, often discarded indiscriminately, can accumulate in soils and alter their chemical and biological properties (Nwachkwu *et al.,* 2011).

Calcium carbide reacts with water to produce acetylene gas and calcium hydroxide, leading to increased soil alkalinity. Elevated pH levels can inhibit microbial activity, disrupt nutrient cycling, and negatively affect soil fertility. Calcium carbide waste is a by-product of the acetylene gas production process primarily composed of calcium hydroxide [$Ca\ (OH)^2$] and other impurities (Atma and Souahi, 2021). This waste may contain heavy metals such as Cu, Pb, Fe, Mn, Ni, and Zn (Ibrahim, 2002). Calcium carbide waste has been reported to exert toxic effects on microorganisms, which may consequently impact higher organisms that rely on microbial activity and their by-products for growth and development (Lavoie, 1980).

Soil microorganisms play essential roles in organic matter decomposition, nutrient mineralization, and soil structure maintenance. Any disruption to microbial communities can therefore have far-reaching ecological consequences. This study aims to evaluate the effects of calcium carbide contamination on soil microbial populations and physicochemical properties.

MATERIAL AND METHODS

Samples Collection

Calcium carbide waste was collected from automobile mechanic workshops in Orji Owerri, Imo State, Nigeria. The samples were air-dried was thoroughly mixed with 1 kg portions of air-dried soil at the following concentrations (w/w): 0% (control, no carbide), 0.5%, 1.0%, 2.0% and 5.0% . Soil was dug up from a farm in Orji Owerri Imo State, Nigeria with no recorded incidence of carbide pollution. The treated soils were placed in perforated plastic pots (to allow aeration) and incubated at room temperature (28 ± 2°C) for 30 days under laboratory conditions.

Preparation of Media

Two different media were used for the analysis, which include Nutrient agar and MacConkey agar and Potato dextrose Agar. The media were prepared according to the manufactures' procedures.

Determination of pH

A 20 g portion of the soil sample was weighed into a 100 mL glass beaker, and 20 mL of sterile distilled water was added. The suspension was stirred continuously for 30 minutes and then allowed to stand for an additional 30 minutes to facilitate settling. Prior to measurement, the pH meter (Hanna Instruments) was calibrated using standard buffer solutions of pH 4.0, 7.0, and 9.0. The electrode was then immersed in the supernatant, and the pH value was recorded once a stable reading was obtained.

Determination of Electrical Conductivity

A 20 g portion of the fresh soil sample was weighed into a 100 mL glass beaker, and 20 mL of sterile distilled water was added. The suspension was stirred continuously for 30 minutes and then allowed to stand undisturbed for an additional 30 minutes to facilitate settling. Soil electrical conductivity was measured using a digital conductivity meter by immersing the electrode in the supernatant, and the value was recorded once a stable reading was obtained.

Gram Staining Techniques

A thin smear was prepared by emulsifying a small portion of a 24-hour-old pure culture in a drop of sterile distilled water on a grease-free glass slide. The smear was air-dried and heat-fixed by gently passing it over a flame. The slide was then placed on a staining rack and flooded with crystal violet (primary stain) for 60 seconds, followed by the addition of Gram's iodine (mordant) for another 60 seconds. The smear was rinsed gently with water and decolorized with 70% ethanol for 60 seconds, then rinsed again and allowed to air-dry. The prepared slide was examined under a microscope using the oil immersion objective (×100). Gram-positive cells appeared purple, while Gram-negative cells appeared red (Nwachukwu et al., 2011).

Identification of Fungal Isolates

Identification of fungi was carried out using Sabouraud dextrose agar (SDA). Serial dilution of the samples was performed as previously described, and aliquots were plated using the pour plate technique. The inoculated plates were incubated at 30°C for 4 days, after which fungal colonies were counted. Fungal isolates were identified based on their colonial and microscopic morphological characteristics, following standard procedures described by de Hoog et al. in the *Atlas of Clinical Fungi*.

Determination of Total Organic Carbon

The total organic carbon (TOC) content of each soil sample was determined using the method described by Walkley (2017).

Determination of Total Nitrogen

Total nitrogen content of the soil samples was determined using the micro-Kjeldahl digestion and colorimetric method as described by Bremner and Mulvaney (2012). The digested samples were analyzed colorimetrically at 630 nm using a spectrophotometer.

Determination of Available Phosphorus

Available phosphorus was determined using a standard colorimetric method. Five grams (5 g) of soil sample were used for the analysis. The absorbance of the resulting solution was measured at 660 nm using a spectrophotometer. (Olsen and Sommers, 1982).

Determination of Cation Exchange Capacity (CEC)

Cation exchange capacity was determined using the ammonium acetate method. Five grams (5 g) of air-dried soil were placed in a plastic bottle, and 100 mL of neutral 1 M ammonium acetate was added. The mixture was shaken on a mechanical shaker for 30 minutes. The exchangeable cations (Na^+, Ca^{2+}, K^+, and Mg^{2+}) in the filtrate were determined using a flame photometer, with ammonium acetate serving as the blank (Thomas, 1982).

Soil Preparation

Loamy soil was collected from a depth of 1–30 cm, bulked, homogenized, and sieved through a 2 mm mesh. Two thousand grams (2000 g) of the processed soil were weighed using an analytical balance and dispensed into seven experimental buckets. Each bucket was amended with calcium carbide at rates of 0 g, 10 g, 50 g, 100 g, 200 g, 400 g, and 800 g, respectively, and thoroughly mixed to ensure uniform distribution. The buckets were appropriately labeled according to the quantity of carbide added, corresponding to concentrations of 0, 5, 25, 50, 100, 200, and 400 g/kg of soil. The impact of carbide contamination was monitored weekly over a period of four weeks at room temperature (28 ± 2°C).

Microbiological Analysis

The bacterial density and diversity were determined by estimation of the population of different groups of bacteria and identification of the heterotrophic bacteria.

Estimation of Total Heterotrophic Bacteria (THB)

Water samples were prepared by transferring 1 mL of each sample into 9 mL of sterile distilled water to obtain a 10^{-1} dilution. The mixture was vigorously shaken for 60 seconds. Serial tenfold dilutions were subsequently prepared using sterile distilled water. Aliquots (1 mL) from dilutions 10^{-4} to 10^{-6} were aseptically inoculated in triplicate for bacterial enumeration. Nutrient agar was used as the culture medium, and the pour plate technique was employed. Two uninoculated plates served as controls. All inoculated plates were incubated at ambient temperature for 48 hours. Population of heterotrophic bacteria in the impacted and control soil samples were enumerated as described by Ihejirika *et al.,* 2014

Identification of bacterial isolates.

Bacterial isolates were identified using conventional methods based on their morphological, biochemical and physiological characteristics. The following biochemical and test were carried out to identify test organisms from sample.

Statistical Analysis

SPSS was used to carry out a paired sample T-test to analyze the data and make inferences.

Results

The effects of calcium carbide on the physicochemical and microbiological properties of soil were evaluated in a controlled laboratory experiment. Soil samples were treated with calcium carbide at concentrations of 0% (control), 0.5%, 1.0%, 2.0%, and 5.0% (w/w) and incubated at 28 ± 2°C for

30 days. All analyses were performed in triplicate, and data are presented as mean ± standard error. One-way ANOVA followed by Duncan's multiple range test was used to separate means at $P < 0.05$. Values with the same superscript letters within a row are not significantly different.

Physicochemical Properties

Application of calcium carbide significantly altered the physicochemical properties of the soil (Table 1). Soil pH increased progressively from 6.45 in the control to 8.67 in the 5.0% treatment, reflecting the alkaline nature of calcium hydroxide released from carbide hydrolysis. Electrical conductivity (EC) also rose significantly, indicating increased ionic strength. Organic carbon and total nitrogen declined with higher carbide concentrations, while available phosphorus and exchangeable calcium increased markedly. Exchangeable potassium and magnesium showed moderate reductions at higher doses.

Table 1: Physicochemical properties of soil treated with different concentration of calcium carbide.

Treatment (% w/w)	pH (1:2.5)	EC (µS cm^{-1})	Organic C (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable Ca (cmol kg^{-1})	Exchangeable K (cmol kg^{-1})
0 (Control)	6.45 ± 0.05^{a}	128 ± 4^{a}	1.32 ± 0.03^{a}	0.148 ± 0.008^{a}	14.2 ± 0.6^{a}	3.85 ± 0.12^{a}	0.42 ± 0.02^{a}
0.5	6.82 ± 0.04^{b}	152 ± 6^{b}	1.25 ± 0.02^{b}	0.142 ± 0.007^{a}	16.8 ± 0.7^{b}	4.92 ± 0.15^{b}	0.39 ± 0.03^{ab}
1.0	7.35 ± 0.06^{c}	189 ± 5^{c}	1.18 ± 0.04^{c}	0.131 ± 0.006^{b}	19.5 ± 0.9^{c}	6.14 ± 0.18^{c}	0.35 ± 0.02^{b}
2.0	7.98 ± 0.03^{d}	234 ± 8^{d}	1.05 ± 0.03^{d}	0.115 ± 0.005^{c}	23.7 ± 1.1^{d}	7.86 ± 0.21^{d}	0.31 ± 0.01^{c}
5.0	8.67 ± 0.05^{e}	312 ± 11^{e}	0.89 ± 0.02^{e}	0.092 ± 0.004^{d}	29.4 ± 1.4^{e}	9.75 ± 0.25^{e}	0.26 ± 0.02^{d}

Microbiological Properties

Calcium carbide application exerted a strong inhibitory effect on soil microbial populations (Table 2). Total heterotrophic bacterial counts declined significantly in a dose-dependent manner, dropping by over 90% at the highest concentration. Fungal populations showed a similar trend, with complete suppression observed at 5.0% carbide. Actinomycete counts followed the same pattern, indicating broad-spectrum antimicrobial activity consistent with the bactericidal and fungicidal effects of acetylene and elevated pH.

Table 2: Microbiological properties (× 10^6 CFU g^{-1} dry soil) of soil treated with different concentrations of calcium carbide.

Treatment (% w/w)	Total Heterotrophic Bacteria	Total Fungi
0 (Control)	48.6 ± 2.1^a	14.3 ± 0.8^a
0.5	39.4 ± 1.7^b	11.8 ± 0.6^b
1.0	27.1 ± 1.9^c	8.4 ± 0.5^c
2.0	12.5 ± 1.2^d	3.9 ± 0.4^d
5.0	3.8 ± 0.6^e	0.0 ± 0.0^e

The observed reductions in microbial abundance were statistically significant ($P < 0.05$) across all carbide treatments compared to the control.

DISCUSSION

The results of this study clearly demonstrate that calcium carbide application induces profound changes in both the physicochemical and microbiological properties of soil from the Automobile mechanic Shop Orji Owerri, Imo State. These alterations are primarily driven by the rapid hydrolysis of calcium carbide (CaC_2) upon contact with soil moisture, which generates acetylene gas (C_2H_2) and calcium hydroxide ($Ca(OH)_2$). The latter is a strong base responsible for the observed dose-dependent increase in soil pH from 6.45 (control) to 8.67 at 5.0% (w/w) carbide (Table 1). This alkaline shift aligns with findings from previous study on calcium carbide waste dumpsites, where elevated pH was attributed to the same mechanism and persisted long after disposal (Ihejirika *et al.,* 2014). Although the work of Lavoie (1980), who observed a high alkaline pH (about 11.2) of the waste which similar to our study.

Concomitant with the pH rise was a significant elevation in electrical conductivity (EC), reflecting increased ionic strength from Ca^{2+} and OH^- ions. Similar increases in EC have been reported in soils amended with calcium carbide residue (CCR) used for geotechnical stabilization, in contact Han *et al.,* 20214 reduced the electrical conductivity (EC). Organic carbon and total nitrogen declined progressively with higher carbide concentrations, likely due to the suppression of microbial activity that normally drives organic matter decomposition and nitrogen cycling. This reduction in soil organic matter is consistent with the toxic effects of carbide waste on heterotrophic microorganisms documented in earlier studies (Okechi *et al.,* 2014; Zhu *et al.,* 2022).

Available phosphorus and exchangeable calcium increased markedly (Table 1), which can be explained by the liming effect of $Ca(OH)_2$ that enhances P solubilization and directly supplies Ca^{2+}. These nutrient enhancements at moderate doses mirror reports where low levels of carbide waste (e.g., 20 g kg^{-1}) improved maize growth and yield, possibly by correcting soil acidity and boosting nutrient availability in tropical soils. However, exchangeable potassium and magnesium showed moderate reductions at higher doses, potentially resulting from cation displacement by excess Ca^{2+} or increased leaching under elevated pH conditions. Such imbalances highlight a potential long-term risk to soil fertility despite short-term Ca and P gains (Kekere *et al.,* 2024).

The microbiological result (Table 2) revealed a strong dose-dependent inhibition of total heterotrophic bacteria, fungi, and actinomycetes, with near-complete suppression at 5.0% carbide. This broad-spectrum toxicity is consistent with the bactericidal and fungicidal properties of acetylene gas and the alkaline environment created by carbide hydrolysis, which disrupt microbial cell membranes, enzyme activity, and metabolic processes. Previous studies on carbide waste dumpsites and cave ecosystems have similarly reported drastic reductions in bacterial and fungal populations up to 81% depression in heterotrophic microbes within hours of exposure (Ihejirika *et al.,* 2014). Semikolennykh *et al.* (2012) demonstrated the toxic effects of spent carbide on microorganisms, reporting that a 0.5% solution of the waste induced bacterial cell death within 10 minutes.

The observed decline in microbial abundance in the present study exceeds that reported in some field dumpsite surveys, where residual carbide still supported low but detectable counts (1.8–2.5 × 10^5 CFU g^{-1} bacteria). This difference may stem from the controlled laboratory conditions and freshly applied carbide used here, which likely produced higher initial concentrations of toxic intermediates compared to weathered dumpsite residues.

Overall, while low-to-moderate carbide application may offer temporary liming benefits in acidic tropical soils (as noted in some agronomic trials), the present findings corroborate the majority of environmental toxicology literature indicating that uncontrolled or high-dose exposure leads to soil degradation through alkalization, microbial biodiversity loss, and nutrient imbalances. These changes could impair long-term soil ecosystem functioning, including nutrient cycling, organic matter turnover, and plant-microbe symbioses critical for sustainable agriculture in regions in the South East Region.

CONCLUSION

Calcium carbide significantly modifies the physicochemical and microbiological properties of soil in a concentration-dependent manner. It elevates soil pH and EC, increases available phosphorus and exchangeable calcium, but reduces organic carbon, total nitrogen, and exchangeable potassium/magnesium. Most critically, it exerts strong inhibitory effects on soil microbial populations, leading to substantial declines in bacteria, fungi, and actinomycetes. These alterations, driven by the production of $Ca(OH)_2$ and acetylene, confirm the toxicological risks associated with calcium carbide waste and highlight its potential to compromise soil health and fertility when applied indiscriminately. The results are largely consistent with previous studies on carbide waste dumpsites and microbial toxicity, though they contrast with limited reports of agronomic benefits at very low doses.

Recommendations

Strict regulations should be enforced to prevent the indiscriminate disposal or application of calcium carbide waste in agricultural soils, given its demonstrated negative impacts on microbial communities and nutrient balance. Farmers and industries should adopt safer fruit-ripening methods (e.g., ethylene generators) and environmentally friendly soil amendments to avoid carbide-related contamination.Further research is recommended on bioremediation techniques (e.g., organic matter addition or microbial inoculants) to restore carbide-contaminated soils.

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