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The Effect of Mycoremediation on the Physicochemical Properties of Hydrocarbon-Polluted Soils of Niger Delta, Nigeria

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Abstract

Crude oil exploration and pipeline vandalism have left extensive areas of the Niger Delta contaminated with petroleum hydrocarbons, degrading soil quality and constraining agricultural productivity. This study evaluated the effectiveness of mycoremediation—the use of fungi to degrade organic pollutants—in restoring the physicochemical properties of hydrocarbon-polluted soil sampled from an impacted site in Ogoniland, Rivers State. A completely randomized design was used, comprising four treatments (uninoculated control, and soil inoculated separately with Aspergillus niger, Penicillium chrysogenum, and Pleurotus ostreatus) replicated three times and incubated for 90 days under laboratory microcosm conditions. Soil pH, electrical conductivity, total organic carbon (TOC), total petroleum hydrocarbon (TPH), total nitrogen, available phosphorus, and moisture content were measured at 0, 30, 60, and 90 days and analyzed using one-way ANOVA with Duncan's Multiple Range Test. All three fungal treatments significantly reduced TPH relative to the control by day 90 ($p < .001$), with Pleurotus ostreatus achieving the greatest reduction (78.4%), followed by Penicillium chrysogenum (69.1%) and Aspergillus niger (65.6%), compared with only 17.6% attenuation in the control. Fungal treatments were also associated with significant improvements in pH, total nitrogen, and available phosphorus relative to the control, consistent with the release of nutrients as hydrocarbons were metabolized. These findings demonstrate that mycoremediation, particularly using ligninolytic white-rot fungi such as P. ostreatus, offers an effective, low-cost, and environmentally compatible approach for restoring hydrocarbon-degraded soils in the Niger Delta and warrants field-scale evaluation.

mycoremediation, hydrocarbon pollution, physicochemical properties, Pleurotus ostreatus, Niger Delta, soil restoration

Background

Decades of crude oil exploration, pipeline vandalism, and inadequate spill response have left large expanses of the Niger Delta contaminated with petroleum hydrocarbons. A United Nations Environment Programme assessment of Ogoniland alone documented hydrocarbon contamination persisting in soil and groundwater decades after some spills occurred, with severe consequences for soil fertility, crop yields, and community livelihoods (Federal Ministry of Environment, 2011). Hydrocarbon contamination alters fundamental soil physicochemical properties: it depresses pH, disrupts nutrient cycling by immobilizing nitrogen and phosphorus, elevates carbon-to-nitrogen ratios, reduces moisture retention, and coats soil particles in ways that impede root penetration and microbial activity (Chikere et al., 2011; Ite & Ibok, 2013).

Bioremediation—the use of living organisms to degrade or detoxify environmental pollutants—has emerged as a cost-effective alternative to physicochemical remediation methods such as excavation and incineration, which are expensive and can themselves cause secondary environmental disturbance (Vidali, 2001). Among bioremediation approaches, mycoremediation exploits the extracellular ligninolytic enzyme systems of certain fungi, including manganese peroxidase, lignin peroxidase, and laccase, which fungi such as Pleurotus species produce to degrade complex lignocellulosic material and which exhibit broad substrate specificity toward the aromatic ring structures found in petroleum hydrocarbons (Singh, 2006). Purnomo et al. (2010) demonstrated that Pleurotus ostreatus effectively degraded the persistent organic pollutant DDT in contaminated soil, while filamentous fungi such as Aspergillus and Penicillium species have been separately documented to degrade a range of aliphatic and aromatic petroleum fractions through both enzymatic and biosurfactant-mediated mechanisms (Okoh, 2006).

Despite this documented degradation potential, most Nigerian bioremediation research on Niger Delta soils has emphasized bacterial bioaugmentation and phytoremediation (Atagana, 2011; Ijah & Antai, 2003), with comparatively fewer studies directly comparing multiple fungal species and systematically tracking the resulting changes in soil physicochemical properties rather than hydrocarbon concentration alone. Because soil physicochemical recovery, not merely pollutant removal, ultimately determines whether contaminated land can return to agricultural use, this distinction matters for translating remediation research into practical land restoration guidance.

Purpose of the Study

This study evaluated the effect of mycoremediation, using three fungal species applied separately, on the physicochemical properties of hydrocarbon-polluted soil from the Niger Delta over a 90-day incubation period. Specifically, it tested the hypothesis that soil inoculated with Aspergillus niger, Penicillium chrysogenum, or Pleurotus ostreatus would show significantly greater improvement in pH, total organic carbon, total petroleum hydrocarbon, total nitrogen, available phosphorus, and moisture content relative to an uninoculated control.

Materials and Methods

Soil Sampling and Study Site

Composite topsoil samples (0–15 cm depth) were collected from a crude-oil-impacted site in Ogoniland, Rivers State, an area with a documented history of pipeline spillage (Federal Ministry of Environment, 2011). Samples were pooled, air-dried, sieved (2 mm mesh), and homogenized before baseline physicochemical characterization, summarized in Table 1, which confirmed substantially elevated total petroleum hydrocarbon (TPH) and depressed pH, nitrogen, and phosphorus relative to typical unpolluted regional soils.

Table 1

Baseline Physicochemical Properties of the Hydrocarbon-Polluted Soil

Parameter	Value (Mean ± SD)	Reference/Unpolluted Soil
pH (H_2O)	5.62 ± 0.14	6.40 ± 0.11
Electrical conductivity (µS/cm)	312 ± 18	104 ± 9
Total organic carbon (%)	8.74 ± 0.62	2.15 ± 0.24
Total petroleum hydrocarbon (mg/kg)	18,420 ± 940	< 50
Total nitrogen (%)	0.09 ± 0.02	0.18 ± 0.03
Available phosphorus (mg/kg)	4.18 ± 0.51	9.62 ± 0.87
Moisture content (%)	14.30 ± 1.20	18.60 ± 1.05

Note. Values are means of triplicate determinations ± standard deviation. Reference values represent typical unpolluted soil from an adjacent, non-impacted site.

Fungal Isolates and Experimental Design

Three fungal species—Aspergillus niger, Penicillium chrysogenum, and Pleurotus ostreatus—were obtained as pure cultures, sub-cultured on potato dextrose agar, and confirmed by standard morphological and microscopic identification prior to use. A completely randomized design was adopted with four treatments: T0 (uninoculated control), T1 (A. niger), T2 (P. chrysogenum), and T3 (P. ostreatus), each replicated three times. For each replicate, 2 kg of polluted soil was placed in perforated polyethylene microcosm containers and inoculated with 10% (w/w) actively growing fungal spawn, except for the control, which received an equivalent volume of sterile, uninoculated growth medium. Microcosms were incubated at ambient laboratory temperature (28–30 °C) for 90 days, with moisture maintained at approximately 60% water-holding capacity by periodic addition of sterile distilled water.

Soil Analysis and Statistical Methods

Subsamples were collected from each microcosm at 0, 30, 60, and 90 days for physicochemical analysis. Soil pH and electrical conductivity were determined in a 1:2.5 soil-to-water suspension using a calibrated pH/EC meter; total organic carbon by the Walkley-Black wet oxidation method; total petroleum hydrocarbon by gravimetric analysis following solvent extraction; total nitrogen by the micro-Kjeldahl method; available phosphorus by the Bray-2 method; and moisture content gravimetrically after oven-drying at 105 °C. Data were analyzed using one-way analysis of variance (ANOVA) at each sampling interval, with Duncan's Multiple Range Test (DMRT) used for post hoc mean separation where the overall F-test was significant, at $\alpha = .05$.

Results

Total Petroleum Hydrocarbon Degradation

TPH concentrations declined across all treatments over the 90-day incubation, but the rate and magnitude of decline differed markedly by treatment, as shown in Table 2. The control showed only modest natural attenuation, declining from 18,420 mg/kg to 15,180 mg/kg (17.6% reduction) by day 90, whereas all three fungal treatments produced significantly greater reductions at every sampling interval from day 30 onward ($p < .001$). By day 90, P. ostreatus achieved the largest reduction (78.4%, to 3,980 mg/kg), followed by P. chrysogenum (69.1%, to 5,690 mg/kg) and A. niger (65.6%, to 6,340 mg/kg); mean separation confirmed that P. ostreatus differed significantly from both other fungal treatments, which did not differ significantly from each other at day 90.

Table 2

Total Petroleum Hydrocarbon (mg/kg) by Treatment Across the 90-Day Incubation

Treatment	Day 0	Day 30	Day 60	Day 90
Control (uninoculated)	18,420[a]	16,850[a]	15,760[a]	15,180[a]
Aspergillus niger	18,420[a]	13,240[b]	9,110[b]	6,340[b]
Penicillium chrysogenum	18,420[a]	12,680[b]	8,470[b]	5,690[b]
Pleurotus ostreatus	18,420[a]	10,050[c]	5,220[c]	3,980[c]

Note. Values are treatment means (n = 3). Means within a column not sharing a superscript letter differ significantly at $p < .05$ (Duncan's Multiple Range Test).

Physicochemical Property Recovery

Table 3 presents the full set of physicochemical parameters at day 90. Soil pH increased from a baseline of 5.62 to 5.78 in the control but rose considerably more in fungal treatments, reaching 6.68 in the P. ostreatus treatment, approaching the reference unpolluted value of 6.40. TOC declined most sharply in the P. ostreatus treatment (3.22%), consistent with active mineralization of hydrocarbon-derived carbon, while total nitrogen and available phosphorus increased significantly in all fungal treatments relative to the control, suggesting that nutrient immobilization associated with hydrocarbon contamination was being reversed as fungal activity proceeded. Moisture content also improved significantly in fungal treatments, though differences among the three fungal species were not significant for this parameter.

Table 3

Soil Physicochemical Properties by Treatment at Day 90

Parameter	Control	A. niger	P. chrysogenum	P. ostreatus	p
pH	5.78[a]	6.35[b]	6.41[b]	6.68[c]	< .001
TOC (%)	8.02[a]	5.14[b]	4.87[b]	3.22[c]	< .001
TPH (mg/kg)	15,180[a]	6,340[b]	5,690[b]	3,980[c]	< .001
Total N (%)	0.10[a]	0.16[b]	0.17[b]	0.21[c]	.002

Available P (mg/kg)	4.30[a]	6.85[b]	7.12[b]	8.94[c]	< .001
Moisture (%)	13.90[a]	16.20[b]	16.55[b]	17.80[b]	.014

Note. Means within a row not sharing a superscript letter differ significantly at $p < .05$ (Duncan's Multiple Range Test). TOC = total organic carbon; TPH = total petroleum hydrocarbon.

Discussion

This study demonstrated that mycoremediation substantially accelerated both hydrocarbon degradation and the recovery of soil physicochemical properties relative to natural attenuation alone. The superior performance of Pleurotus ostreatus is consistent with its well-documented ligninolytic enzyme system, which enables oxidation of complex aromatic hydrocarbon structures that many bacteria and non-ligninolytic fungi cannot readily attack (Singh, 2006), and parallels findings by Purnomo et al. (2010) for a different class of persistent organic pollutant. The comparatively smaller, though still substantial, reductions achieved by A. niger and P. chrysogenum align with prior reports that these genera degrade hydrocarbons primarily through cytochrome P450 monooxygenase pathways and biosurfactant production rather than extracellular ligninolytic oxidation (Okoh, 2006), a mechanistic difference that may explain their comparatively lower efficiency against the heavier hydrocarbon fractions likely present in this weathered, long-contaminated soil.

The parallel improvement in pH, total nitrogen, and available phosphorus alongside TPH reduction supports the interpretation that hydrocarbon degradation and nutrient cycling recovery are mechanistically linked rather than independent outcomes: as fungi metabolize hydrocarbon carbon, they simultaneously immobilize and later release nutrients previously locked in microbial biomass, while the removal of hydrophobic hydrocarbon coatings on soil particles likely improved moisture retention and aeration (Chikere et al., 2011). These findings extend the Niger Delta bioremediation literature, previously dominated by bacterial and phytoremediation studies (Atagana, 2011; Ijah & Antai, 2003), by demonstrating that fungal treatment, and white-rot fungi in particular, can address both pollutant removal and the broader physicochemical degradation that limits agricultural reuse of contaminated land.

This study was conducted under controlled laboratory microcosm conditions using soil from a single sampling site, which may not fully capture the variability of field conditions, including

fluctuating temperature, rainfall, and indigenous microbial competition that could affect fungal establishment and activity at larger scale. The 90-day duration, while sufficient to demonstrate substantial treatment effects, does not indicate whether further degradation would occur with extended incubation or whether restored soils could sustain crop growth. Future research should evaluate consortium treatments combining multiple fungal species, assess performance under field conditions across multiple Niger Delta sites, and directly test the agronomic viability of remediated soil through plant bioassays.

Conclusion

Mycoremediation, particularly using the white-rot fungus Pleurotus ostreatus, significantly outperformed natural attenuation in reducing total petroleum hydrocarbon concentrations and restoring pH, nitrogen, phosphorus, and moisture properties in hydrocarbon-polluted Niger Delta soil over a 90-day period. These findings support fungal bioaugmentation as a viable, low-cost component of soil restoration strategies for oil-impacted communities, though field-scale trials and agronomic validation are needed before large-scale deployment.

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