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CRUDE OIL POLLUTION DOSE-DEPENDENTLY DEGRADES SOIL CHEMICAL FERTILITY AND MICRONUTRIENT AVAILABILITY

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Introduction

Crude oil contamination of agricultural soils is a persistent environmental concern in petroleum-producing regions, including Nigeria's Niger Delta, where oil spills and other petroleum-related activities can alter soil chemical properties and threaten agricultural productivity. Petroleum hydrocarbons interact with soil matrices and may modify pH, nutrient availability, and biogeochemical processes that support plant growth (Raimi *et al.,* 2022a; 2022b; Clinton-Ezekwe *et al.,* 2024; Omidiji *et al.,* 2026; Tomquin *et al.,* 2026). Although previous studies have documented nutrient depletion in hydrocarbon-contaminated soils, evidence from controlled concentration gradients remains limited, particularly for less frequently examined soil chemical constituents. The present study therefore evaluated changes in soil chemical properties across a controlled gradient of crude oil contamination, with emphasis on nutrient availability and soil acidity. The findings are relevant to soil health, sustainable agriculture, and environmental management in oil-impacted landscapes. The study aimed to quantify changes in selected soil chemical properties following controlled exposure to different concentrations of crude oil. Specifically, it assessed concentration-associated changes in soil pH, total nitrogen, phosphorus, phosphate, calcium, potassium, magnesium, sodium, nitrate and nitrite, and evaluated the implications of these changes for soil fertility and agricultural sustainability.

Methodology

A controlled pot experiment was conducted using soil amended with crude oil at four concentrations: 0% (control), 5%, 7.5% and 10% (w/w), with five replicates per treatment. Following a two-week controlled weathering/incubation period, soil samples were collected and analysed. Soil pH was determined using a soil–water slurry and calibrated pH meter. Total nitrogen

was measured by the Kjeldahl method; phosphorus and phosphate were determined using colorimetric methods; calcium, potassium and sodium were analysed by flame photometry; magnesium was determined by atomic absorption spectrophotometry; and nitrate and nitrite were assessed using standard colorimetric procedures. Treatment means and standard errors were calculated. Differences among treatment groups were evaluated using analysis of variance (ANOVA), followed by Duncan's multiple range test (DMRT), with statistical significance defined as $p < 0.05$.

Results

Crude oil contamination was associated with substantial changes in soil chemical properties, although the magnitude and direction of change varied among parameters. Soil pH declined progressively from 4.80 ± 0.012 in the control to 4.70 ± 0.012, 4.62 ± 0.012, and 4.58 ± 0.0115 at 5%, 7.5%, and 10% crude oil, respectively, indicating progressive acidification. Total nitrogen decreased from 12.53 ± 1.300 mg/kg in the control to 1.17 ± 0.0115 mg/kg at 10%, corresponding to a 90.7% reduction. Phosphorus declined from 6.10 ± 1.154 to 1.39 ± 0.207 mg/kg (77.2%), while phosphate showed an initial increase from 8.32 ± 0.577 mg/kg in the control to 9.21 ± 1.154 mg/kg at 5%, followed by declines to 5.51 ± 1.155 and 1.54 ± 0.015 mg/kg at 7.5% and 10%, respectively. Thus, phosphate did not exhibit a strictly monotonic concentration-response pattern. Calcium declined from 145.0 ± 1.154 to 98.50 ± 0.987 mg/kg (32.1%), potassium from 93.70 ± 1.115 to 30.63 ± 0.742 mg/kg (67.3%), and magnesium from 7.32 ± 1.154 to 1.11 ± 0.012 mg/kg (84.8%) between the control and 10% treatment. Sodium decreased from 8.44 ± 1.154 to 2.42 ± 1.001 mg/kg, representing a 71.3% reduction. Nitrate exhibited a non-monotonic response, increasing from 3.32 ± 1.154 mg/kg in the control to 3.87 ± 0.719 mg/kg at 5%, before declining to 1.61 ± 0.079 and 0.86 ± 0.002 mg/kg at 7.5% and 10%, respectively. Nitrite declined from 1.56 ± 0.577 to 0.71 ± 0.001 mg/kg (54.5%). The reported ANOVA/DMRT analysis indicated statistically significant treatment effects at $P < 0.05$; however, the available results do not provide sufficient statistics to quantify effect sizes or establish a linear dose-response for every parameter. The most pronounced reductions at 10% crude oil occurred for total nitrogen (90.7%), magnesium (84.8%), phosphate (81.5%), phosphorus (77.2%), nitrate (74.1%), sodium (71.3%), and potassium (67.3%). Calcium showed the smallest reduction (32.1%), while nitrite decreased by 54.5%. The concentration gradient therefore produced substantial deterioration in several indicators of soil chemical fertility, but the responses were not uniformly monotonic. In particular, the transient increases in phosphate and nitrate at 5% indicate that individual soil constituents may respond differently to petroleum contamination, potentially reflecting changes in chemical availability and transformation processes rather than simple proportional depletion.

Conclusion

Controlled crude oil contamination was associated with marked alterations in soil acidity and nutrient-related chemical properties. Increasing crude oil concentration corresponded with progressive acidification and substantial reductions in total nitrogen, phosphorus, potassium, calcium, magnesium, and sodium at the highest exposure level. However, phosphate and nitrate exhibited non-monotonic responses, demonstrating that the effects of petroleum contamination cannot appropriately be characterized as a uniform linear decline across all soil constituents. The findings provide quantitative evidence that crude oil contamination can impair several components of soil chemical fertility and support the inclusion of multiple soil indicators in assessment and remediation programmes. Because the experiment was conducted under controlled pot conditions over two weeks, extrapolation to long-term field conditions should be made cautiously. Environmental management of oil-impacted agricultural soils should prioritize rapid containment of crude-oil releases and subsequent site-specific assessment of soil chemical condition. Remediation strategies, including bioremediation, phytoremediation and appropriate soil amendments, should be evaluated experimentally according to contamination intensity and soil characteristics. Monitoring programmes should include pH and multiple nutrient indicators rather than relying on a single chemical measure, particularly because individual constituents may exhibit

different response patterns. Longitudinal field studies should assess whether the observed changes persist, recover or intensify during natural weathering and whether they translate into measurable effects on crop establishment, productivity and soil biological function. Future experiments should also incorporate larger sample sizes, longer observation periods, and appropriate effect-size estimates to strengthen inference regarding concentration-response relationships.

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