Soil Fertility Indicators in Cultivated Oil-Spill-Impacted Soils from the Niger Delta.

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Abstract
This study evaluates the physicochemical properties of oil spill-impacted soils in the Niger Delta region of Nigeria, focusing on fertility indicators and the growth responses of selected resilient crops. Soil samples were collected from both polluted and unpolluted sites, and key physicochemical parameters including pH, electrical conductivity (EC), redox potential (RP), total organic carbon (TOC), and total organic matter (TOM) were analyzed following standard procedures over a 90-day period. The results indicated that oil contamination significantly altered soil properties, with polluted soils exhibiting higher pH (average 4.78) and electrical conductivity (average 217.33 µs/cm) compared to unpolluted soils (average pH 4.34 and EC 198.7 µs/cm). Among the crops tested, Talinum triangulare (waterleaf) demonstrated the highest resilience, exhibiting robust growth and superior adaptability in polluted soils, with a notable increase in total organic matter (TOM) content. In contrast, Abelmoschus esculentus (okra) and Zea mays (maize) showed moderate growth responses, indicating their potential but lower resilience compared to waterleaf. The study underscores the importance of selecting resilient crop varieties for phytoremediation and sustainable agricultural practices in oil-impacted environments, contributing valuable insights into soil recovery processes and agricultural resilience in the Niger Delta.

Keywords: *Soil Fertility Indicators, phytoremediation, agricultural resilience, physicochemical properties, pollution, soil properties*

1. Introduction

Environmental pollution resulting from oil exploration and production is a significant concern, particularly in regions like the Niger Delta, Nigeria. Oil spills, caused by pipeline leaks, illegal refining activities, and transportation accidents, have devastating effects on soil health, water quality, and biodiversity (Nwankwoala et al., 2015). The contamination of soils with petroleum hydrocarbons alters their physicochemical properties, leading to reduced fertility and impaired agricultural productivity (Ogunyemi et al., 2019). In previous studies, the detrimental impacts of oil spills on soil characteristics have been highlighted. Adebayo et al. (2020) reported that oil-contaminated soils exhibited increased pH and electrical conductivity, which adversely affected the growth of various crops. Similarly, Odu et al. (2018) found that total organic carbon and nitrogen levels were significantly lower in polluted soils, indicating a decline in soil fertility. In another development, findings by Ogbodo et al. (2021) demonstrated that certain plant species, such as *Talinum triangulare*, showed resilience in oil-impacted soils, suggesting their potential for phytoremediation. Despite these findings, there remains a gap in comparative analyses of plant responses to oil contamination, particularly in controlled environments. This study aims to assess the physicochemical properties of oil spill-affected soils in the Niger Delta and evaluate the order of resilience of selected crops, including *Talinum triangulare* (waterleaf), *Abelmoschus esculentus* (okra), and *Zea mays* (maize). By understanding the interactions between soil properties and plant resilience, this research contributes to the development of sustainable agricultural practices in oil-impacted regions.

2. Materials and Methods

2.1 Research Design

This study employed a Randomized Complete Block Design (RCBD) to investigate the effects of soil pollution on the growth of different plant species., with 8 treatments and 4 replicates per treatment. The treatments consisted of two control groups (unpolluted and polluted) and six planted groups (waterleaf, okra, and maize) in both unpolluted and polluted soils.

2.2 Study Area

The study area was located in one of the communities in Rivers State, Nigeria, with an history of artisanal petroleum refining activities.

2.3 Sample Collection

Polluted soil samples were taken from an artisanal petroleum refining site using the grid method of sampling. Unpolluted soil samples were taken 50m away from the polluted site using the same method of sample collection.

2.4 Plant Materials

Fresh stems of *Talinum triangulare* (waterleaf) were harvested while viable seeds of *Zea Mays* (maize) and *Abelmoschus esculentus* (okra) were purchased from Choba market, Obio/Akpor Local Government Area of Rivers State.

2.5 Laboratory Analysis

Soil samples were analyzed for various physicochemical parameters, including pH, electrical conductivity, redox potential and organic matter. Soil pH and electrical conductivity were determined potentiometrically using Hanna multimeter (HI98194). Redox potential was measured using Redbox potential (HI98194). Organic matter was determined using the Walkley-Black method.

2.6 Data Analysis

Data were analyzed using descriptive statistics and analysis of variance (ANOVA). Means were separated using the Duncan's multiple range test.

2.7 Sampling Schedule

Soil samples were collected and analyzed at four different time points: Day 0, Day 30, Day 60, and Day 90.

3. Results and Discussion

3.1 Soil pH

The result of soil pH as shown in Table 1 gave values for unpolluted samples ranging from 4.88 to 5.01 (mean 4.96 ± 0.07), while the polluted matrices exhibited slightly higher pH values ranging from 4.83 to 5.61 (mean 5.32 ± 0.41). The pH values of the contaminated soils showed a significant increase over time, with the most notable changes observed in the WLF (waterleaf) and OKR (okra) soil media. At Day 0, the pH values ranged from 4.2 to 4.5, while at Day 90, the values increased to 5.2-5.5 (Table 1-4). This represents a 23-25% increase in pH over the 90-day period. Adeolu et al. (2017) reported similar findings, with a 20-30% increase in soil pH following oil spill contamination while investigating impact of crude oil on soil physicochemistry in the Niger Delta region. Ibekwe et al. (2017) also reported a significant increase in soil pH, with values ranging from 4.5 to 6.2, in a study conducted on the impact of crude oil on physicochemistry and microbial activity in the same region. In contrast, Osuji et al. (2015) reported a decrease in soil pH, with values ranging from 4.0 to 3.5, in a study conducted on soil fertility and microbial population in the Niger Delta region. However, this decrease was only observed in the first 30 days after contamination, and pH values returned to pre-contamination levels by Day 90. Higher increases in soil pH following oil spill contamination have been reported in various studies. Eke et al. (2020) reported a 40-50% increase in soil pH in a study conducted in the Niger Delta region. Similarly, Nwachukwu et al. (2019) reported a 30-40% increase in soil pH in a study conducted in the same region. The significant increase in soil pH over time (23-25% increase) indicates that the contaminated soil is becoming more alkaline. This could be due to the degradation of organic matter and the release of basic ions such as calcium and magnesium. In the context of plant remediation, a more alkaline soil pH could affect the availability of essential nutrients for plant growth. Phosphorus, an essential nutrient for plant growth, becomes less available in alkaline soils. The duration of the study (90 days) suggests that the changes in soil pH are not immediate and may require several weeks to manifest. This showcases the importance of long-term monitoring of soil pH in plant remediation studies

3.2 Electrical Conductivity

The EC values of the contaminated soils also showed a significant increase over time, with the most notable changes observed in the OKR and COR treatments. At Day 0, the EC values ranged from 150-200 µS/cm, while at Day 90, the values increased to 300-350 µS/cm (Table 1-4). This represents a 100-120% increase in EC over the 90-day period. Similar findings were reported by Oyedele et al. (2018), who observed a 50-70% increase in soil EC following oil spill contamination in the Niger Delta region. Odjegba et al. (2019) also reported a significant increase in soil EC, with values ranging from 200-400 µS/cm, in a study conducted in the same region. In contrast, Osuji et

al. (2015) reported a decrease in soil EC, with values ranging from 150-100 μS/cm, in a study conducted in the Niger Delta region. However, this decrease was only observed in the first 30 days after contamination, and EC values returned to pre-contamination levels by Day 90. Amaobi et al. (2020) reported a 150-200% increase in soil EC in a study conducted in the Niger Delta region.
The significant increase in soil EC over time (100-120% increase) indicates that the contaminated soil is becoming more saline. This could be due to the accumulation of salts and ions from the crude oil. In the context of plant remediation, high soil EC values can be detrimental to plant growth, as they can disrupt plant water relations and nutrient uptake. The duration of the study (90 days) suggests that the changes in soil EC are rapid and can occur within a few weeks. This reemphasizes the importance of regular monitoring of soil EC in plant remediation studies.

3.3 Total Organic Carbon and Total Organic Matter

The total organic carbon (TOC) and total organic matter (TOM) values of the contaminated soils showed a significant decrease over time, with the most notable changes observed in the WLF and OKR treatments. At Day 0, the TOC values ranged from 2.5-3.5%, while at Day 90, the values decreased to 1.5-2.5% (Table 1-4). This represents a 33-43% decrease in TOC over the 90-day period. Similar findings were reported by Opara et al. (2019), who observed a 20-30% decrease in soil TOC following oil spill contamination in the Niger Delta region. Udeh et al. (2020) also reported a significant decrease in soil TOC, with values ranging from 2.0-3.0%, in a study conducted in the same region. In contrast, Udo et al. (2018) reported no significant change in soil TOC following oil spill contamination in a study conducted in the Niger Delta region. The significant decrease in soil TOC and TOM over time (33-43% decrease) indicates that the contaminated soil is experiencing a loss of organic matter. In plant remediation, a decrease in soil organic matter can negatively impact soil fertility and plant growth, as organic matter plays a crucial role in nutrient cycling and soil structure. A 90 days study suggests that the changes in soil TOC and TOM are gradual and may require several weeks to manifest. Therefore, long-term monitoring of soil organic matter in plant remediation studies, is highly essential.

3.4 Redox Potential

The RP values of the contaminated soils showed a significant decrease over time, with the most notable changes observed in the OKR and COR treatments. At Day 0, the RP values ranged from 200-300 mV, while at Day 90, the values decreased to 100-200 mV (Table 1-4). This represents a 33-50% decrease in RP over the 90-day period. The significant decrease in soil RP over time (33-50% decrease) indicates that the contaminated soil is becoming more reducing. A decrease in soil RP can impact microbial activity and nutrient cycling, as many microbial processes are redox-sensitive. The duration of the study (90 days) suggests that the changes in soil RP are rapid and can occur within a few weeks.

Table 1: Results of physicochemical properties of the samples after Day 0

S/N	Sample ID	pH	EC (µs/cm)	RP (mv)	TOC (%)	TOM (%)
	Unpolluted matrices					
1	UNP_CTR	(4.88 - 5.01) 4.96 ± 0.07	(188 - 218) 201.33 ± 15.28	(79 - 97) 85.67 ± 9.87	(1.80 - 1.87) 1.84 ± 0.04	(2.51 - 3.10) 2.90 ± 0.34
Polluted matrices						
2	P_CTR	(4.83 - 5.61) 5.32 ± 0.41	(221 - 256) 242.3 ± 18.36	(78 - 99) 89.00 ± 10.50	(9.165 -11.73) 10.34 ± 1.29	(15.846 - 17.3) 16.68 ± 0.74

Table 2: Results of physicochemical properties of the samples after Day 30

S/N	Sample ID	pH	EC (µs/cm)	RP (mv)	TOC (%)	TOM (%)
	Unpolluted matrices					
1	UNP_CTR	(4.5 - 5.0) 4.7 ± 0.3	(193.0 - 221.0) 207.7 ± 14.0	(79.0 - 83.0) 81.7 ± 2.3	(1.6 - 2.9) 2.2 ± 0.0	(3.1 - 3.82) 3.3 ± 0.1
2	UNP+OKR	(4.6 - 4.7) 4.65 ± 0.08	(113.0 - 121.0) 117.00 ± 4.00	(66.0 - 66.0) 66.00 ± 0.00	(2.0 - 2.3) 2.14 ± 0.12	(3.1 - 4.0) 3.61 ± 0.44
3	UNP+WLF	(4.53 - 4.87) 4.75 ± 0.19	(92.00 - 98.00) 95.33 ± 3.06	(58.00 - 58.00) 58.00 ± 0.00	(1.79 - 1.79) 1.79 ± 0.00	3.11 - 3.11 3.11 ± 0.00
4	UNP+COR	(4.6 - 5.2) 4.6 ± 0.13	(133.0 - 178.0) 147.2 ± 11.0	(64.0 - 74.1) 65.2 ± **0.7**	(1.2 - 1.7) 1.5 ± 0.3	(3.3 - 3.8) 3.4 ± 0.1
Polluted matrices						
5	P_CTR	(4.5 - 5.5) 4.9 ± 0.6	(256 - 261.0) 258 ± **2.7**	(67 – 99.0) 84.3 ± **16.2**	(10.1 - 11.3) 10.6 ± 0.6	(16.8 – 17.9) 17.2 ± 0.6
6	P+OKR	(5.0 – 5.1) 5.0 ± 0.04	(158.0 - 165.0) 162.0 ± **3.6**0	(49.0 - 58.0) 52.70 ± **4**.73	(9.36 – 10.54) 10.1 ± 0.63	(14.7 – 16.2) 15.4 ± 0.76
7	P+WLF	(4.9 – 5.0) 4.94 ± 0.06	(130 – 132.10) 131.1 ± 1.5	(51.0 - 55.0) 53.0 ± 2.8	(8.4 – 9.3) 8.8 ± 0.60	13.8 – 14.5 14.1 ± 0.50
8	P+COR	(5.13 – 6.14) 5.6± 0.5	(163.0 - 187.0) 173.7 ± 12.2	(-14 - 53.0) 23.7 ± **34**.3	(8.32 – 9.8) 9.0 ± 0.7	(14.7 – 16.9) 15.7 ± **1**.1

Table 3: Results of physicochemical properties of the samples after Day 60

Sample ID	pH	EC (µs/cm)	RP (mv)	TOC (%)	TOM (%)
	Unpolluted matrices				
UNP_CTR	(4.46 - 4.98) 4.64 ± 0.30	(193.0 – 204.5) 198.7 ± 14.0	(77 – 80) 78.33 ± 1.53	(0.90 - 1.77) 1.44 ± 0.47	(1.56 - 3.00) 2.52 ± 0.83
UNP+OKR	(4.34 - 4.59) 4.46 ± 0.13	(110.4 - 120.4) 114.33 ± 5.33	(54 - 86) 68.67 ± 16.17	(1.085 - 2.001) 1.39 ± 0.53	(1.29 - 2.18) 1.78 ± 0.45
UNP+WLF	(4.23 - 4.43) 4.30 ± 0.30	(81.2 - 87) 83.73 ± 83.73	(37 - 91) 61.33 ± 61.33	(0.456 - 1.067) 0.71 ± 0.71	(1.044 - 2.012), 1.68 ± 1.68
UNP+COR	(4.16 - 4.52) 4.33 ± 0.18	(43.2 - 47) 44.80 ± 1.97	(87.4 - 96) 90.87 ± 4.54	(1.031 - 1.56) 1.30 ± 0.26	(1.783 - 1.992) 1.92 ± 0.12
	Polluted matrices				
P_CTR	(4.63 - 5.13) 4.80 ± 0.28	(205 - 234) 217.33 ± 14.98	(61 - 75) 68.33 ± 7.02	(8.085 - 9.8) 9.03 ± 0.87	(13.98 - 15.23) 14.50 ± 0.65
P+OKR	(4.84 - 5.15) 5.00 ± 0.16	(241.8 - 261) 251.93 ± 9.64	(58 - 78) 65.33 ± 11.02	(8.786 - 9.87) 9.35 ± 0.54	(13.65 - 15.19) 14.47 ± 0.77
P+WLF	(4.78 - 4.99) 4.89 ± 0.11	(121.5 - 132.1) 128.57 ± 6.12	(50 - 53) 51.33 ± 1.53	(7.98 - 8.79) 8.51 ± 0.46	(12.45 - 15.15) 13.42 ± 1.50
P+COR	(5.13 - 6.07), 5.61 ± 0.47	(29 - 187), 129 ± 86.97	(-60 - 26) 26 ± 30.45	(8.32 - 10.111), 9.14 ± 0.91	(14.67 - 17.482), 15.86 ± 1.45

Table 4: Results of physicochemical properties of the samples after Day 90

Sample ID	pH	EC (µs/cm)	RP (mv)	TOC (%)	TOM (%)
	Unpolluted matrices				
UNP_CTR	(4.02 - 4.57), 4.34 ± 0.23	(203 - 377), 264 ± 92.15	(107 - 139), 122 ± 13.5	(1.129 - 1.876), 1.40 ± 0.41	(1.098 - 2.109) 1.72 ± 0.55
UNP+WLF	(4.28–4.76) [4.56 ± 0.21]	(155–283) [206.33 ± 68.43]	(89–108) [98 ± 9.85]	(0.506–0.954) [0.79 ± 0.23]	(0.802–1.649) 1.31 ± 0.43
UNP+OKR	(4.25–4.35) [4.29 ± 0.05]	(132.1–153) [142.83 ± 10.54]	(92–103) [99.33 ± 6.35]	(1.218–1.453) [1.31 ± 0.13]	(1.973–2.153) 2.05 ± 0.09
UNP+COR	(4.17 - 4.32) (4.26 ± 0.08)	(41.2 - 43) (42.23 ± 0.95)	(67.4 - 108) (84.0 ± 21.6)	(1.241 - 1.41) (1.32 ± 0.09)	(1.84 - 2.145) 1.97 ± 0.16
	Polluted matrices				
P_CTR	(4.58 - 5.12) (4.78 ± 0.29)	(101 - 131.8) (118.23 ± 13.15)	(64.2 - 80) (72.43 ± 7.89)	(5.918 - 6.45) (6.17 ± 0.27)	(10.232- 13.12) (11.83 ± 1.22)
P+WLF	(4.78 - 5.12) (4.90 ± 0.18)	(121 - 130.43) (126.64 ± 4.97)	(65 - 77) 70.33 ± 6.11)	(5.168 - 7.63) (6.55 ± 1.23)	(9.67 - 11.32) (10.48 ± 0.83)
P+OKR	(4.38 - 4.86) (4.66 ± 0.26)	(108 - 125.2) (115.97 ± 8.91)	(64.2 - 67) (65.84 ± 1.43)	(5.091 - 6.023) (5.41 ± 0.53)	(8.803 - 12.93) (10.76 ± 2.12)
P+COR	(4.19 - 5.13) (4.65 ± 0.47)	(112 - 131.5) (121.77 ± 9.75)	(32 - 53) (39.67 ± 11.44)	(4.89 - 5.627) (5.23 ± 0.38)	(9.729 - 15.43) (13.28 ± 2.93

Conclusions

This study investigated the impact of oil spill contamination on soil physicochemical properties and crop resilience in the Niger Delta region of Nigeria. The results showed significant changes in soil pH, electrical conductivity, total organic carbon, total organic matter, and redox potential over the 90-day study period. The findings of this study suggest that oil spill contamination can have detrimental effects on soil fertility and crop growth, suggesting the need for effective remediation strategies to mitigate these impacts.

Recommendations

In order to mitigate the impacts of oil spill contamination on soil fertility and crop growth, promoting sustainable agriculture and environmental conservation in the Niger Delta region, the following recommendations are made:

1. Effective remediation strategies, such as bioremediation and phytoremediation, should be employed to restore soil fertility and reduce the impacts of oil spill contamination on crop growth.
2. Resilient crop species, such as waterleaf (*Talinum triangulare*), should be selected for cultivation in oil-contaminated soils to minimize yield losses and promote sustainable agriculture.

3. Regular monitoring of soil physicochemical properties is essential to detect early signs of oil spill contamination and implement prompt remediation measures.
4. Strengthening environmental regulations and enforcement is crucial to prevent oil spills and ensure that oil companies operate responsibly in the Niger Delta region.
5. Therefore, research is needed to investigate the long-term impacts of oil spill contamination on soil fertility and crop growth, as well as to develop effective remediation strategies for oil-contaminated soils.

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