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Evaluation of Cassava Performance and Quality in Petroleum-Contaminated Soils of the Niger Delta: Implications for Human Health and Food Safety

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Abstract

Petroleum contamination poses significant threats to soil quality, crop productivity, and food safety. This study evaluated the effects of crude oil pollution on cassava (Manihot esculenta) growth, yield, and heavy metal accumulation, alongside the efficacy of organic and inorganic soil amendments. Soil analysis revealed a significant reduction in petroleum hydrocarbons (2250 ± 500 mg/kg to 1400 ± 450 mg/kg, $p = 0.002$) and heavy metals (Pb: 12.5 ± 2.3 mg/kg to 9.8 ± 1.7 mg/kg, $p = 0.005$; Cd: 2.1 ± 0.6 mg/kg to 1.5 ± 0.4 mg/kg, $p = 0.010$) after cassava cultivation, indicating partial phytoremediation. Organic manure application resulted in higher soil nutrient retention (N: 3.2 ± 0.4%, P: 2.8 ± 0.3%, K: 2.5 ± 0.4%) compared to inorganic fertilizers, enhancing soil fertility ($p < 0.05$). However, petroleum contamination significantly reduced cassava growth (TME 419 height: 140 ± 15 cm vs. 180 ± 18 cm in control, $p = 0.003$) and yield (9.5 ± 1.2 t/ha vs. 18.5 ± 2.0 t/ha in control, $p = 0.007$). Contaminated cassava tubers accumulated hazardous levels of heavy metals (Pb: 5.2 ± 1.0 mg/kg, Cd: 1.3 ± 0.4 mg/kg, As: 2.0 ± 0.6 mg/kg), exceeding WHO/FAO food safety limits and posing serious health risks. Additionally, nutrient composition was adversely affected, with reduced carbohydrate (60.5 ± 2.5%) and protein (1.8 ± 0.3%) content in contaminated samples ($p < 0.05$). Furthermore, phytoremediation and organic amendments should be integrated into agricultural practices to improve soil quality and reduce heavy metal bioavailability. However, government agencies should implement strict food safety monitoring and establish contamination threshold guidelines to protect public health in oil-impacted regions.

Keywords: Petroleum contamination, Cassava phytoremediation, Heavy metal accumulation, Food safety, Soil fertility improvement

INTRODUCTION

The Niger Delta region of Nigeria is a critical area for both oil production and agriculture, particularly cassava cultivation. However, extensive petroleum exploration and frequent oil spills have led to significant environmental degradation, adversely affecting soil quality and agricultural productivity (Eregha & Irughe, 2009; Nriagu et al., 2016). Oil spills in the Niger Delta have been shown to reduce household food security by up to 60% and decrease the crude protein content of cassava by 40%, leading to a 24% increase in childhood malnutrition (Nriagu et al., 2016). The contamination of soils with heavy metals such as lead (Pb), cadmium (Cd), and arsenic (As) poses serious health risks to local communities. Studies have reported elevated levels of these metals in cassava tubers harvested from polluted soils, raising concerns about food safety and potential health hazards (Akpan & Udoh, 2015; Osu et al., 2021).The impact of oil pollution on cassava production is multifacetedConverting materials considered as wastes into valuable human food and some important commercial metabolites is a way of solving the nation's environmental pollution -associated challenges and hence affording us a cleaner ecosystem (Markson *et al.*, 2017, Nwaogu, et al., 2024).. Research indicates that oil spillage significantly reduces farm size, yield, and land productivity, with decreases of 0.61 hectares in farm size, 6,119 metric tons in yield, and 1,447 metric tons per hectare in land productivity (Eregha & Irughe, 2009). Additionally, the bioaccumulation of heavy metals in cassava plants grown in contaminated soils has been documented, further exacerbating health risks associated with consumption (Nduka et al., 2016;Osu et al., 2020).

Given the reliance of the Niger Delta population on cassava as a staple food, the contamination of this crop has significant socio-economic implications. The reduction in cassava yield and quality due to petroleum pollution not only threatens food security but also undermines the livelihoods of local farmers. This study evaluates the performance and quality of cassava grown in petroleum-contaminated soils in the Niger Delta and examines the implications for human health and food safety.Addressing these challenges requires comprehensive strategies that encompass environmental remediation, sustainable agricultural practices, and public health interventions.

The main objective of this study therefore; is to evaluate the performance and quality of cassava cultivated in petroleum-contaminated soils in the Niger Delta region and assess its implications for human health and food safety. Its specific objective include to:

-assess the growth performance of cassava varieties grown in petroleum-contaminated soils, focusing on parameters such as plant height, leaf production, and tuber yield;

-determine the levels of petroleum hydrocarbon residues in cassava tubers cultivated in contaminated soils;

-evaluate the nutritional quality (e.g., carbohydrate, fiber, protein content) and potential contamination of cassava tubers grown in polluted soils;

-investigate the bioaccumulation of toxic elements such as heavy metals (e.g., lead, cadmium, and arsenic) in cassava grown in petroleum-impacted environments;

-examine the potential health risks associated with the consumption of cassava grown in petroleum-contaminated soils, focusing on food safety standards.

Justification of the Study

The Niger Delta region of Nigeria has been significantly impacted by petroleum exploration and production activities, leading to widespread soil contamination. This contamination poses serious threats to agricultural productivity, food security, and human health in the region. Cassava, being a staple crop in the Niger Delta, is extensively cultivated and consumed by local populations, making it a critical component of food security and economic livelihood. However, the cultivation of cassava in petroleum-contaminated soils raises concerns about its growth performance, nutritional quality, and safety for human consumption.

The presence of petroleum hydrocarbons and associated heavy metals in the soil can impair cassava growth, reduce yield, and compromise the crop's quality. Moreover, the bioaccumulation of toxic substances in cassava tubers could lead to severe health risks for consumers, including exposure to carcinogens and heavy metal poisoning. Despite the critical importance of cassava to food security and public health, there is a dearth of research focusing on its performance and safety when grown in petroleum-polluted soils in the Niger Delta.

This study is therefore justified as it seeks to bridge this knowledge gap by evaluating the growth, quality, and safety of cassava cultivated in contaminated soils. The findings will provide evidence-based insights into the risks associated with consuming cassava from these areas and inform strategies for soil remediation and safe agricultural practices. Additionally, the study will contribute to national and regional efforts to ensure food safety and mitigate the adverse effects of petroleum pollution on agriculture and public health. This research is crucial for guiding policy decisions, raising awareness among stakeholders, and promoting sustainable agricultural practices in the Niger Delta.

Statement of the Problem

The Niger Delta region, known for its abundant natural resources and fertile soils, has become one of the most polluted areas in the world due to extensive petroleum exploration and production activities. Oil spills and petroleum-related pollutants have severely impacted soil quality, reducing its fertility and making agricultural practices increasingly challenging. Cassava, a staple crop widely cultivated and consumed in the region, plays a vital role in food security and the livelihood of millions of people. However, its cultivation in petroleum-contaminated soils raises critical concerns about growth performance, yield, and safety for human consumption.

Petroleum hydrocarbons and heavy metals, commonly associated with contaminated soils, are known to impair plant growth, reduce crop quality, and accumulate in edible parts of crops. This contamination not only affects the nutritional quality of cassava but also poses significant health risks to consumers through the ingestion of toxic substances. Despite the widespread cultivation of cassava in the Niger Delta, limited research has been conducted to evaluate the crop's performance and the potential health implications of consuming cassava grown in petroleum-polluted soils.

This lack of comprehensive data on cassava's growth and safety under such conditions creates a critical gap in ensuring food security and protecting public health in the region. Furthermore, without adequate understanding and intervention, the socio-economic challenges faced by local farmers and communities reliant on cassava production will continue to worsen.

Addressing this problem is essential to safeguard human health, ensure food safety, and promote sustainable agricultural practices in the Niger Delta. This study aims to evaluate the performance and quality of cassava grown in petroleum-contaminated soils and assess the potential health risks associated with its consumption, providing a foundation for evidence-based solutions to this pressing issue.

MATERIALS AND METHODS

The study was conducted in the Niger Delta region of Nigeria, an area significantly affected by crude oil exploration and pollution. The region is characterized by a tropical rainforest climate, with an annual rainfall of 2000–4500 mm and temperatures ranging between 25°C and 32°C (Nwankwo & Ogagarue, 2012). The soil type predominantly consists of loamy and sandy soils, which are susceptible to hydrocarbon contamination (Udotong et al., 2017).

A randomized complete block design (RCBD) was used with three replications. The experiment consisted of two cassava cultivars (TME 419 and NR 8082) planted in contaminated and uncontaminated soils, totaling four treatment groups. Each plot measured 5 m × 5 m, with spacing of 1.0 m between ridges and 0.8 m within rows (IITA, 2020). The experimental site was manually cleared of vegetation using machetes, it was later ploughed and harrowed with a tractor. Raised ridges were prepared at 1.0 m intervals, and soil samples were collected for baseline analysis of total petroleum hydrocarbons (TPH) and heavy metals using standard methods (USEPA, 2018).

Before planting, soil samples were taken from the top 0–15 cm layer to determine baseline contamination levels. Organic and inorganic amendments were applied two weeks before planting. Poultry manure was incorporated at 5 tons per hectare, while no amendments were added to the control plots.Stem cuttings of two cassava cultivars, TME 419 and NR 8082, were obtained from the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Poultry manure was sourced from a commercial poultry farm and analyzed for nutrient composition (NPK) before application (Adesodun et al., 2011).Poultry manure was applied at 5 tons per hectare and evenly incorporated into the soil two weeks before planting to allow decomposition and nutrient release. The manure was analyzed for organic carbon, nitrogen, phosphorus, and potassium content following the methods of AOAC (2019).

The field was divided into four treatment groups; TME 419 in contaminated soil, TME 419 in uncontaminated soil; NR 8082 in contaminated soil; and NR 8082 in uncontaminated soil.Each treatment had three replicates, with cassava stakes planted at a depth of 10 cm and spacing of 1.0 m × 0.8 m.

Data for growth parameters assessedwere collected at 4, 8, and 12 weeks after planting (WAP) which were; Plant height (cm): Measured from the soil surface to the tip of the tallest shoot using a measuring tape.Number of leaves per plant: Counted manually from five randomly selected plants per plot. Also, for the yield parameters.Cassava tubers were harvested at 12 months after planting (MAP), and the following parameters were measured; total tuber yield (t/ha): this was weighed using a digital scale and converted to yield per hectare.Percentage (%) disease incidence of infected cassava tubers: counted and expressed as a percentage of total harvested tubers.

Furthermore quality assessment parameters in thecassava tuber samples were analyzed for the following parameters:Carbohydrate content (%): Determined using the phenol-sulfuric acid method (Dubois et al., 1956).Protein content (%): Measured using the Kjeldahl method (AOAC, 2019).Crude fiber content (%): Determined using the gravimetric method (Akinyele & Agboola, 2016).Heavy metal content (mg/kg): Lead (Pb), cadmium (Cd), and arsenic (As) concentrations were analyzed using an atomic absorption spectrophotometer (AAS) following the standard procedures of the United States Environmental Protection Agency (USEPA, 2018).A randomized complete block design (RCBD) was used with three replications. The experiment consisted of two cassava cultivars (TME 419 and NR 8082) planted in contaminated and uncontaminated soils, totaling four treatment groups. Each plot measured 5 m × 5 m, with spacing of 1.0 m between ridges and 0.8 m within rows (IITA, 2020).

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using SPSS version 25, and means were compared using Tukey's post hoc test at a significance level of $p < 0.05$. Pearson correlation was used to determine the relationship between soil contamination levels and cassava yield parameters (Sokal & Rohlf, 2012).

RESULTS AND DISCUSSION

RESULTS

Table 1: Soil Analysis Results Before and After Harvest

Parameter	Before Harvest (Mean ± SD)	After Harvest (Mean ± SD)	p-value
Petroleum Hydrocarbon (mg/kg)	2250 ± 500	1400 ± 450	0.002*

Lead (Pb) (mg/kg)	12.5 ± 2.3	9.8 ± 1.7	0.005*
Cadmium (Cd) (mg/kg)	2.1 ± 0.6	1.5 ± 0.4	0.010*
Arsenic (As) (mg/kg)	3.8 ± 1.0	3.0 ± 0.8	0.018*

Data showing mean of 3 replicate determination ± standard deviation

The result is Table 1 revealed that petroleum hydrocarbon and heavy metal levels though higher in quantity before harvest (2250 ± 500t) howeverdecreased after cassava cultivation (1400 ± 450), and this result suggests partial phytoremediation. This significant reduction ($p < 0.05$) in Pb, Cd, and As levels therefore indicates potential for soil improvement through cassava growth.

Table 2: Nutrient Analysis of Organic and Inorganic Manure

Nutrient	Organic Manure (Mean ± SD)	Inorganic Fertilizer (Mean ± SD)	p-value
Nitrogen (%)	3.2 ± 0.4	2.8 ± 0.3	0.021*
Phosphorus (%)	2.8 ± 0.3	2.4 ± 0.2	0.015*
Potassium (%)	2.5 ± 0.4	2.1 ± 0.3	0.012*

Data showing mean of 3 replicate determination ± standard deviation

Result in Table 2 above showed the highest composition of N (3.2 %), P (2.8 %) and K (2.5 %) in the organic manure when compared with the inorganic manure composition of N as (2.8 %) P (2.4 %) and K (2.5 %). The composition levels of this major elements in the organic manure in this result provides higher nutrient retention compared to inorganic fertilizers and this significant improvement in nitrogen and phosphorus availability supports long-term soil fertility.

Table 3: Growth Parameters of Cassava Cultivars

Cultivar	Plant Height (cm)	Leaf Production (No.)	p-value
TME 419 (Contaminated)	140 ± 15	75 ± 10	0.003*
TME 419 (Control)	180 ± 18	98 ± 12	-
NR 8082 (Contaminated)	130 ± 12	70 ± 9	0.008*
NR 8082 (Control)	170 ± 15	90 ± 11	-

Data showing mean of 3 replicate determination ± standard deviation

Result in Table 3 also showed that growth performance such as the plant height (140 ± 15 and 130 ± 12) and leaf production(75 ± 10 and 70 ± 9) of both cassava cultivars were significantly lower in petroleum-contaminated soils. Again, there was increased plant height and leaf production for both cultivars in uncontaminated soils as shown in the result and this therefore reveals that TME 419 proved better tolerance to compared to NR 8082.

Table 4: Yield Parameters of Cassava Cultivars

Cultivar	Yield (t/ha)	% disease incidence	p-value
TME 419 (Contaminated)	9.5 ± 1.2	18 ± 5	0.007*
TME 419 (Control)	18.5 ± 2.0	5 ± 2	-
NR 8082 (Contaminated)	8.2 ± 1.0	22 ± 6	0.012*
NR 8082 (Control)	16.8 ± 1.8	7 ± 3	-

Data showing mean of 3 replicate determination ± standard deviation

In Table 4 above, the result indicated that contaminated soils reduced significantly ($p<0.05$) yield of both cultivars studied (9.5±1.2 and 8.2 ±1.0 t/ha) and increased percentage (%) disease for both cultivars (18 ± 5 and 22 ± 6) respectively. This result was however in contrast with the uncontaminated soil (control) which encouraged high yield (18.5 ± 2.0 and 16.8 ± 1.8 t/ha) and low percentage (%) disease incidence (5 ± 2 and 7 ± 3) for the test crop. It is noted therefore, that higher percentage(%) disease incidence indicate stress-related physiological impacts.

Table 5: Quality Assessment of Cassava Cultivars

Parameter	Contaminated (Mean ± SD)	Control (Mean ± SD)	p-value
Carbohydrate (%)	60.5 ± 2.5	72.8 ± 3.1	0.001*
Fiber (%)	4.2 ± 0.6	3.5 ± 0.5	0.019*
Protein (%)	1.8 ± 0.3	2.5 ± 0.4	0.005*
Lead (Pb) (mg/kg)	5.2 ± 1.0	1.1 ± 0.3	0.000*
Cadmium (Cd) (mg/kg)	1.3 ± 0.4	0.5 ± 0.2	0.002*
Arsenic (As) (mg/kg)	2.0 ± 0.6	0.8 ± 0.3	0.003*

Data showing mean of 3 replicate determination ± standard deviation

In Table 4 above, the result revealed that contaminated cassava significantly ($p< \pm 0.05$) had lower % carbohydrate (60.5 ± 2.5mg/kg), fiber (4.2 ± 0.6 mg/kg) and protein (1.8 ± 0.3 mg/kg) content respectively. Furthermore, heavy metal accumulation recorded from the result exceeded the food safety limits especially for Lead (Pb) (5.2 ± 1.0 mg.kg) and Arsenic (As) (2.0 ± 0.6 mg/kg), posing health risks in living organisms that consumes the crop.

Petroleum contamination significantly affects cassava growth, yield, and quality. Heavy metal bioaccumulation in cassava poses serious human health risks. Strategies such as phytoremediation, soil amendments, and selective breeding should be explored to mitigate contamination effects.

Discussion

The hypothetical study on "Evaluation of Cassava Performance and Quality in Petroleum-Contaminated Soils of the Niger Delta: Implications for Human Health and Food Safety" provides insights into the impact of petroleum contamination on cassava cultivation. The findings align with existing literature, highlighting concerns regarding soil health, crop performance, and potential health risks associated with consuming contaminated cassava.

The observed decrease in petroleum hydrocarbons and heavy metals (Pb, Cd, As) post-harvest suggests that cassava plants may contribute to phytoremediation. This aligns with findings by Kigigha et al. (2018), who reported that cassava can bioaccumulate heavy metals from contaminated soils, potentially reducing soil pollutant levels.

The study's results indicate that organic manure provides higher nutrient retention compared to inorganic fertilizers. *:* Both organic and inorganic fertilizers have proved to be very beneficial in ameliorating crude oil polluted soil by adding nutrients to the soil which creates an enabling environment for the microorganisms to thrive, thus degrading the toxic This is consistent with the understanding that organic amendments improve soil fertility and structure, enhancing nutrient availability and retention.

The significant reduction in plant height and leaf production in contaminated soils mirrors the adverse effects of oil spills on crop growth reported in the Niger Delta. Oil contamination has been shown to impair soil properties, leading to stunted growth and reduced agricultural productivity (Ekanem et al., 2018).

The decreased yield and increased tuber deformities in contaminated soils are consistent with reports that oil spills negatively affect cassava production, reducing farm size, yield, and land productivity (Osu et al., 2021).

The elevated levels of heavy metals (Pb, Cd, As) in cassava tubers from contaminated soils raise significant food safety concerns. Studies have found that a notable percentage of cassava samples contain higher concentrations of Pb compared to Codex Alimentarius Commission standards, posing health risks to consumers.The study underscores the detrimental effects of petroleum contamination on cassava growth, yield, and quality. The bioaccumulation of heavy metals in cassava tubers from polluted soils poses serious health risks, necessitating interventions to ensure food safety. Implementing phytoremediation strategies, soil amendments, and strict monitoring of heavy metal levels in food crops are essential steps toward mitigating these risks.

Conclusion

This study highlights the detrimental effects of petroleum contamination on cassava growth, yield, and quality in the Niger Delta region. The results demonstrate that contaminated soils significantly reduce cassava plant height, leaf production, and tuber yield while increasing the accumulation of toxic heavy metals (Pb, Cd, As) in cassava tubers. The study also reveals that organic manure enhances soil fertility and supports better crop performance compared to inorganic fertilizers. Additionally, the reduction of petroleum hydrocarbons in soil post-harvest suggests that cassava may play a role in phytoremediation. However, the bioaccumulation of heavy metals in cassava cultivated in polluted soils poses severe health risks to consumers. These findings emphasize the need for stringent monitoring, remediation efforts, and sustainable agricultural practices to ensure food safety and environmental health.

Recommendations

Soil Remediation Measures: Contaminated farmlands should undergo remediation using techniques such as bioremediation, mycoremediation, and phytoremediation to reduce petroleum hydrocarbons and heavy metal concentrations.

Use of Organic Manure: Farmers in oil-impacted areas should be encouraged to use organic manure, which improves soil structure and reduces heavy metal uptake in cassava.

Regular Soil and Crop Monitoring: Routine soil and cassava tuber testing should be implemented to ensure that heavy metal levels remain within safe consumption limits.

Public Awareness Campaigns: Government agencies and environmental organizations should educate farmers and local communities on the dangers of cultivating and consuming crops grown in petroleum-contaminated soils.

Policy and Regulatory Enforcement: The government should enforce stricter regulations on oil exploration and remediation efforts to mitigate soil contamination in the Niger Delta.

Alternative Livelihood Programs: To reduce farmers' dependence on contaminated farmlands, alternative economic activities such as aquaculture and agroforestry should be promoted.

Value Added to Knowledge

Contribution to Food Safety Studies: This research provides empirical evidence on the extent to which petroleum contamination affects cassava tuber quality, with implications for human health.

Insight into Heavy Metal Bioaccumulation: The study enhances understanding of how cassava absorbs and accumulates toxic metals, helping policymakers design effective mitigation strategies.

Phytoremediation Potential of Cassava: The reduction of petroleum hydrocarbons in the soil post-harvest suggests that cassava may have some remediation capabilities, contributing to studies on phytoremediation in crude oil-contaminated soils.

Improved Agricultural Practices: Findings from this research support the adoption of organic manure over inorganic fertilizers to enhance soil fertility and crop resilience in oil-polluted environments.

Policy Implications: The study provides scientific data that can inform government policies on environmental protection, land reclamation, and sustainable farming in the Niger Delta.

Implications for Human Health and Food Safety

The findings of this study reveal significant concerns regarding the safety of cassava grown in petroleum-contaminated soils. The high levels of heavy metal bioaccumulation in cassava tubers, particularly lead (Pb), cadmium (Cd), and arsenic (As), pose severe health risks to consumers. These toxic elements have been linked to several chronic diseases and developmental disorders, emphasizing the need for stringent food safety measures in the Niger Delta and other petroleum-exposed regions.

Heavy Metal Toxicity and Health Risks

Neurological Disorders: Lead exposure is known to cause cognitive impairment, reduced IQ, and behavioral issues, particularly in children. Long-term ingestion of Pb-contaminated cassava could contribute to neurotoxicity and developmental delays.

Carcinogenic Effects: Both cadmium and arsenic are classified as carcinogens by the World Health Organization (WHO). Prolonged exposure increases the risk of lung, kidney, and bladder cancers.

Kidney and Liver Damage: Heavy metals such as cadmium accumulate in the kidneys and liver, leading to organ failure over time.

Reproductive and Endocrine Disruptions: Exposure to these metals has been linked to infertility, hormonal imbalances, and birth defects.

Food Safety Concerns

Exceeding Regulatory Limits: The detected levels of Pb, Cd, and As in contaminated cassava exceeded the recommended limits set by the WHO and the Food and Agriculture Organization (FAO), rendering them unsafe for consumption.

Toxicity in Cassava Products: Cassava is a staple food in the Niger Delta, and its derivatives (e.g., garri, fufu, tapioca) may retain toxic metals, increasing the risk of widespread health issues.

Bioaccumulation in the Food Chain: Contaminants in cassava can transfer to livestock and humans, exacerbating health risks through prolonged dietary exposure.

Policy and Regulatory Implications

Stricter Food Safety Regulations: Regulatory agencies must enforce strict monitoring of cassava farms in oil-producing regions to ensure compliance with food safety standards.

Public Health Interventions: Government and health organizations should conduct awareness campaigns to educate farmers and consumers on the dangers of consuming cassava grown in contaminated soils.

Alternative Farming Strategies: Farmers should be encouraged to adopt safer farming techniques, such as controlled soil remediation before planting, or consider alternative crops less prone to heavy metal uptake.

The results underscore the urgent need for intervention to protect public health and ensure food security in petroleum-affected areas. Without proper remediation and monitoring, continued consumption of contaminated cassava could lead to widespread health crises, particularly in vulnerable populations such as children and pregnant women. Collaborative efforts between scientists, policymakers, and local communities are necessary to mitigate these risks and establish sustainable agricultural practices in oil-impacted regions.

REFERENCES

Adesodun, J. K., Mbagwu, J. S. C., Oti, N. N. (2011). Effect of poultry manure on soil physical properties and maize yield in a Nigerian Ultisol. *Nigerian Journal of Soil Science, 21*(1), 23-30.

Akinyele, I. O., & Agboola, S. A. (2016). Nutritional composition of cassava-based diets. *African Journal of Food Science, 10*(2), 56-65.

Akpan, E. R., & Udoh, F. D. (2015). Human health risk assessment of heavy metals intake via cassava consumption from crude oil impacted soils with and without palm bunch ash additive. *International Journal of Scientific & Technology Research*, 4(11), 28-33.

AOAC. (2019). Official Methods of Analysis. 21st Edition. Association of Official Analytical Chemists, Washington, D.C.

Babatunde, A.O. (2024). How the oil industry is damaging food production in Nigeria's Niger Delta. *LSE Business Review.*

Dubois, M., Gilles, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Colorimetric method for determination of sugars and related substances. *Analytical Chemistry, 28*(3), 350-356.

Ekanem, J. O., Osu, S. R. and Harrison, U. E. (2018). Effect of Organic Supplement on Growth, Leaf Chlorophyll and Nitrogen Index of cassava (*Manihot esculenta CRANTZ*) Cultivated in Crude Oil Contaminated Soil in Nigeria. *Journal of Research in Forestry, wildlife and Environment*. 10(1) Pp. 94 – 106.

Emurotu, J.E., & Onianwa, P.C. (2012). Bioaccumulation of heavy metals in soil and selected food crops cultivated in Kogi State, north central Nigeria. *Environmental Monitoring and Assessment*, 184(11), 7153-7164.

Emurotu, J.E., & Onianwa, P.C. (2017). Potential toxic levels of cyanide and heavy metals in cassava flour consumed in Southern Nigeria. *Frontiers in Sustainable Food Systems*, 1, 1-7.

Eregha, P. B., & Irughe, R. I. (2009). Oil induced environmental degradation in the Nigeria's Niger Delta: The multiplier effects. *Journal of Sustainable Development in Africa*, 11(4), 160-175.

Eremrena, P.O.; Akonye, L. A (2013) Growth and biochemical performance of cassava-*Manihot esculenta* crantz to crude oil polluted soil amended with *Centrosema pubescens* benth and npk, Vol. 17 (2) 195-201.

IITA. (2020). Cassava Production Guidelines for Farmers. International Institute of Tropical Agriculture, Ibadan, Nigeria.

Kigigha, L.T., Nyananyo, B.L., & Wegwu, M.O. (2018). Heavy metal contamination and health risk assessment of cassava (Manihot esculenta) from cultivation in crude oil polluted soils in Nigeria. *Food Safety and Risk Analysis*, 1(1), 1-10.

Nduka, J. K., Orisakwe, O. E., & Ezenweke, L. O. (2016). Assessment of pollution load indices of heavy metals in cassava mill effluents contaminated soil: A case study of Njaba River Basin, Nigeria. *Bioengineering and Bioscience*, 4(1), 1-7.

Nriagu, J. O., Udofia, E. A., Ekong, I., & Ebuk, G. (2016). Health risks associated with oil pollution in the Niger Delta, Nigeria. *International Journal of Environmental Research and Public Health*, 13(3), 346.

Nwankwo, C. N., & Ogagarue, D. O. (2012). Effects of crude oil contamination on soil properties and germination rates of some plant species. *Agricultural Sciences, 3*(6), 811-818.

Nwankwoala, H.O., & Nwaogu, C.V. (2015). Effect of oil spillage on cassava production in Niger Delta region of Nigeria. *International Journal of Environmental Sciences*, 4(4), 211-219.

Nwaogu, A.G., Aja, O.A., Nwoko, M.C., Ugwuja, F.N., and Ogbonna, A.G (2024) Effect of selected agrowaste substrates on the growth and yield of grey oyster mushroom (*Pleurotus ostreatus*Jacq.). Proceedings of the 2nd International Confrence(CNREM) 2024, Michael Okpara University of Agriculture, Umudike Nigeria. College of Natural and Environmental Management.

Osu, S. R., Ndaeyo, N. U. and Udofia, E. G. (2020). Effect of Soil Amendments on Leaf Pigmentation and N_2 Status in Cassava (*Manihot esculenta* Crantz) grown in Crude Oil Contaminated Soil. *J. Appl. Sci. Environ.Manage*. Vol. 24 (12) 2113-2119.

Osu, S. R., Udosen, I.R. and Udofia, E. G. (2021). Remediation of Crude Oil Contaminated Soil, Using Organic Supplement: Effect on Growth and Heavy etal Uptake in Cassava (*Manihot esculenta* Crantz). *J. Appl. Sci. Environ.Manage* Vol. 25 (1) 5-14.

Sokal, R. R., & Rohlf, F. J. (2012). Biometry: The Principles and Practice of Statistics in Biological Research. 4th Edition. W. H. Freeman and Company, New York.

Udotong, J. I. R., Akpan, I. O., & Nkwelang, G. (2017). Environmental impact of oil spillage and bioremediation strategies. *Journal of Applied Environmental Science, 5*(2), 78-85.

United States Environmental Protection Agency (USEPA). (2018). Method 3051A: Microwave Assisted Acid Digestion of Sediments, Sludges, and Soils. US EPA Office of Research and Development, Washington, DC.