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Phytoremediation: A Tool For Curbing The Oil Spill Menace In The Niger Delta Region

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ABSTRACT
Crude oil exploration, exploitation, processing, and transportation lead to the major environmental pollution in the Niger-Delta. The polluted environment usually becomes less useful and habitable for agro life and other activities like recreation and the soil organisms and soil dependent organisms are adversely affected which call for restoration. The adequate protection and restoration of contaminated soils require their characterization and remediation. Phytoremediation is an environmentally friendly method used during the last few decades to eliminating organics pollutants from soil, sediment, and water. It was clear that the potential to use phytoremediation was an efficient technology in the restoration of crude oil contaminated sites. Broadly, phytoremediation alters soil organic matter content and soil pH, which are important variables associated with many soil processes. It was recommended that the dynamic relationships between all soil properties should not be overlooked following soil remediation.
Keywords: Phytoremediation, oil spill, exploration, bioremediation, Niger Delta

INTRODUCTION

Occasions of an oil spill are a common sight in the Niger Delta Region of Nigeria and several communities have suffered the devastating effect of such spills. In the end, it is the local communities located around such oil installations that bear the brunt. The spills are sometimes caused by several factors including poorly maintained infrastructures located around high-pressure oil pipelines. When accidents occur, these pipelines get damaged and spill off their content (Edemhanria, 2014). Activities of oil bunkers where local people break into pipelines and wells to steal the content have resulted in damaged pipelines thereby leaving them to leak. In many cases, types of equipment and facilities of oil multinationals often fail due to poor maintenance.

Crude oil exploration, exploitation, processing, and transportation lead to the major environmental pollution in the Niger-Delta (Nicolloti & Eglis, 1998). The polluted environment usually becomes less useful and habitable for agro life and other activities like recreation and the soil organisms and soil dependent organisms are adversely affected (Siddiqui & Adams, 2002; Lundstedt, 2003). The crude oil polluted soil has changed soil properties due to the hydrophobic behavior of oil which results in the reduction of water and nutrient availability (Bossert & Bartha, 1985). Crude oil pollution also leads to high mechanical resistance in the soil which slows down root elongation (Bengough, 2003). Crude oil contamination can also alter the soil moisture conditions and due to the hydrophobic nature of oil, water spreads in homogenously oil-contaminated soils (Merckl et al., 2005). This leads to water deficiency is such soils.

Apart from affecting the soil, crude oil spill affects the growth of plants. According to Merckl et al. (2005a, b) crude oil leads to the elimination of vegetation cover and subsequent soil erosion. Merckl et al.

(2004a, b) reported that crude oil pollution reduces the rate of seedling emergence and growth of plants. The work of Agbogidi et al. (2006) showed that a high concentration of crude oil inhibits the germination of *Dennettia tripetala*. Similar reports were also made by Udo and Oputa (1984), Gills et al. (1992), Anoliefo and Vwioko (1994), and Siddiqui and Adams (2002).

Therefore, soil contamination through industrial production, human activities, improper waste disposal, or environmental accidents has become a serious concern that threatens human health and ecosystems. Today, many contaminated sites are often tainted with a complex mixture of organic and inorganic compounds, including petroleum hydrocarbons (PHC), pesticides, trace elements (TE) such as lead (Pb), copper (Cu), Zinc (Zn), mercury (Hg) and cadmium (Cd). Many of these compounds are a major concern for plants, animals, and human beings due to their detrimental biological effects, toxicity, carcinogenicity, mutagenicity, and teratogenicity. Petroleum hydrocarbons and Trace element contaminated soil may pose risks and hazards to humans and the ecosystem through; direct ingestion, or contact with soil, the food chain (soil-plant-human or soil-plant-animal-human), drinking of contaminated groundwater, and reduction of land usability.

Today, international and local civil society organizations are calling on the Federal Government and oil multinationals to set aside funds, which can be administered independently, for dealing with oil spills in the Niger Delta. The civil society groups are also calling for the establishment of an independent body that should be funded through environmental insurance bond is based on the agreed percentage of the oil revenue. A prompt response mechanism needs to be put in place to curtail oil spills and address critical social needs brought about by such incidents.

The adequate protection and restoration of contaminated soils require their characterization and remediation. In the last decade, efforts have been made towards the reduction of pollutants directly at the source and the establishment of new environmental guidelines for contaminated site remediation. Several technologies such as physical, chemical, and biological techniques have been developed to remediate these sites. These technologies include the source control (in situ and ex situ treatment) and the containment remedies. Generally, these approaches have limitations i.e. the high costs, the applicability to high contaminant concentrations, the applicability to mixed wastes (organics and inorganics), and the irreversible changes in soil physicochemical properties. Despite a large number of articles dealing with phytoremediation, only a few papers have been published assessing the efficiency of phytoremediation using both chemicals and ecotoxicological analysis. However, the paper focuses on the remediation of contaminated soil using non-destructive, less disruptive to the soil, and lowcost technologies.

The Menace of the Oil Spill in Niger Delta

The oil and gas sector is a significant portion of the Nigerian economy (Gazi, 2012). Scholars believe crude oil production has become more relevant in contemporary times as there is yet no cheaper alternative to it as a form of energy. Interestingly, the sector has also been asserted to cause the most significant chunk of Nigerian environmental pollution. The oil and gas sector is a significant portion of the Nigerian economy (Gazi, 2012). Scholars believe crude oil production has become more relevant in contemporary times as there is yet no cheaper alternative to it as a form of energy. Interestingly, the sector has also been asserted to cause the most significant case of Nigerian environmental pollution.

It is also believed that the spill has negatively affected the existence of Shell Fish in the Niger Delta waters (Amnesty International, 2012). Substantiating the report, it has been observed that shellfish have disappeared in the K-Dere area of Bodo West in Ogoniland and this has been attributed to the oil spills on the waters in that region (Oyende 2012). Even more, the disappearance of Cockles for the same reason (Amnesty International, 2009). Cumulatively, these oil spills on the Niger Delta waters inhibit the ability of Niger Delta indigenes to resort to their water system for their livelihood activities of fishing (Oyende 2012). Notably, several Niger Delta indigenes rely on fishing for their sustenance and survival. A recent study of the United Nations Environmental Programme (UNEP) found that drinking water in Ogoniland (a native name for the Niger Delta), contained a known carcinogen at levels 900 times above World Health Organisations (WHO) guidelines (UNEP, 2011).

Also, it is a known fact that the people of the Niger Delta region, nay most other parts of Nigeria, rely on agriculture for food and their livelihood (Oyende 2012). Interestingly, it has been reported that oil pipelines run across farmlands; and other oil infrastructure, such as wellheads and flow stations, are often close to agricultural land (Amnesty International, 2009). It is therefore easy for a spill to destroy viable crops of Niger Delta farmers. A study found that oil spills in the Niger Delta region reduce the ascorbic content of vegetables by an estimate of 36% and the crude protein content of cassava by an estimate of 40%, thus resulting in a 24% increase in the prevalence of childhood malnutrition in the region. Other scholars have posited that emissions from the combustion of associated gas contain toxins such as benzene, nitrogen oxides, dioxin, etc. which increase air prone disease risk, insecurity of food and, damage to the weather (Werner, Vink & Watt, 2015).

It is further asserted that oil spills on land also cause the ground to become toxic and this constitutes a danger to plants and animals who feed on these materials [6].

Petroleum is the mixture of a different chemical compound such as polychlorinated biphenyl (PCB), TE, PAH which know to pose harmful effects on the quality of life. Aromatics hydrocarbons are a major concern because of their toxicity and tendency to bioaccumulation (Wrenn and Venosa 1996). This is because they are poorly soluble in water but very soluble in oil and fat (Singh 2006a). Indeed, the solubility of the aromatic compounds in water decreases with increasing molecular weight (Wild and Jones 1995). Therefore, due to their hydrophobicity, PAH remains in the aquatic environment to the surface of water or adsorbed to the surface of the sediment and form a reservoir (Borja et al. 2005).

Based on the structure and mechanism of activation, many PAH exhibit mutagenic, tumorigenic, and carcinogenic properties (Singh 2006b). In soil, they can also adhere to organic matter and in this case, they are not available for microorganisms, plants, or leaching (Wild & Jones 1995). US Environment Protection Agency (EPA; www.epa.gov) provides complete removal of 16 specific PAH: acenaphthene, acenaphthylene, anthracene, benz (a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, benzo(k)fluoranthene, chrysene, dibenz (a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, naphthalene, phenanthrene, and pyrene listed among the 126 priority pollutants and 5 of them are listed among the 25 hazardous substances thought to pose the most significant potential threat to human health (Pazos et al. 2010).

Phytoremediation

Phytoremediation is a bioremediation technique in which vegetation is used to remove, detoxify, or stabilize organic contaminants in soil (Gan, Von Lau & Ng, 2009), and it includes the processes of phytoextraction, phytostabilization, phytovolatilization, phytodegradation, or rhizodegradation (Lim, Von Lau & Poh, 2016). This method may be especially appealing to remediation practitioners because it employs soil function (e.g., biomass production, waste management) to reduce contaminant concentration. However, like other bioremediation options, phytoremediation is slow, has varying success at removing contaminants, and it cannot be applied at very high concentration levels at which plant growth may be diminished or even absent. Further, the benefits of phytoremediation are generally confined to the root zone, so the depth of treatment is dependent on the rooting structure of the vegetation. The specific impacts of phytoremediation may vary slightly based on the method of implementation; some reviews (Tomei & Dauglis, 2013; Azubuike, Chikere & Okpokwasili, 2016) offer descriptions of each method, as well as advantages and disadvantages. The most common consequence of bioremediation is the accumulation of toxic compounds formed by incomplete degradation of PHCs (Mikkonen, Hakala, Lappi, Kondo, & Vaalam, 2012). These intermediate products, which usually are not identifiable by traditional total petroleum hydrocarbon (TPH) or polycyclic aromatic hydrocarbon (PAH) tests, may still cause soil toxicity; therefore, these tests may not be the best indicators of remediation success. For example, naturally attenuated soils that met Australian safety guidelines for TPH levels still exhibited toxicity to earthworms and radish plants (Sheppard, Adetutu, Makadia, & Ball, 2011). In a bioaugmentation study, intermediate degradation metabolites initially decreased wheat growth and increased ecotoxicity; ecotoxicity began to decline after 24 days, although it persisted throughout the 40-

day study (Shen, Zu, Cui, Wang, Dang & Wu 2015). Similarly, the accumulation of these products has led to increased cytotoxicity in bioreactor treatments (Aldrion, Singleton, Nakamura, Shea & Aitken, 2016). However, the bioavailability of these compounds was very low following bioreactor treatment, so the immediate risk was reduced.

Beyond increased soil toxicity, further effects of bioremediation on soil properties are dictated by the addition and incorporation of organic amendments (e.g., composting) because SOM (which is comprised of 50–58% SOC) is so valuable in regulating many soil characteristics (Larney & Angers, 2012). Increasing SOM through the application of compost increases aggregate stability, porosity, and water holding capacity (Barzegar, Yousefi & Daryashenas,2002), as well as reduces susceptibility to compaction. Although few bioremediation studies identified these parameters, these benefits may be assumed on remediation projects that increased SOC (Wang, Wang, Zhang, Li, & Guo, 2015). Further, microbial degradation rates of organic compounds increase as SOM increases. This degradation forms residual acidic products, so pH is also affected by SOM dynamics.

A land farm project incorporating cotton stalks in the soil increased SOC from 2.33 to 6.74%, which accompanied a drop in pH from 8.6 to 7.1 (Wang, Wang, Zhang, Li, & Guo, 2015). Similarly, bio-piles inoculated with a microbial consortium and sawdust had greater degradation of TPHs (80%) and lower pH (6.5) than those without sawdust (33%; 7.2) (Ma, Yang, Dai, Chen, Deng & Zhou, 2016). However, mechanical agitation often employed in bioremediation projects may contribute to SOC loss, as even a non-contaminated treatment in a biopile study had SOC decrease from 4.6 to 2.8% after 400 days (Dawson, Godsiffe, Thompson, Ralebitso-Senior, Killham KS, Paton, 2007). Therefore, applying organic amendments may not only be a valuable way to encourage bioremediation and regulate soil pH, but it may also be necessary to retain SOC levels. This need is evident in a land farm project that did not add compost, in which SOM decreased up to 40% and soil pH increased from 7.3 to 8.3 (Besalatpour, Hajabbasi, Khoshgoftarmanesh & Dorostka, 2011).

Also, vegetation production is associated with additional alterations to soil properties. Notably, root growth improves porosity, and root exudates can stimulate aggregate formation (Pedron & Petruzzelli, 2011). These aggregates may stabilize SOM in phytoremediation sites, as dissolved organic carbon (DOC) decreased under a range of operating conditions (Hamdi, Benzarti, Aoyama & Jedid, 2012; Marchand, Hogland, Kaczala, Jani, Marchand & Augustsson, 2016). Similarly, phytoremediation may decrease the mobility of contaminants and heavy metals in the soil through the process of phytostabilization. Vegetation is generally associated with increasing SOM, which typically results in lower soil pH. However, this trend does not hold true in all phytoremediation studies. Soil pH increased from 5.7 to 7.1 in PAH-contaminated soils producing alfalfa (Hamdi et al., 2012), as well as in fuel-contaminated soils growing galega (*Galega orientalis*) (from 5.7 to 6.2) (Mikkonnen, Kondo, Lappi, Wallenius, Lindstrom & Hartikainen, 2011) suggesting a neutralizing effect on soil pH of acidic soils.

The improved physical and chemical properties for soil microorganisms are also supplemented by root exudates that stimulate microbial growth (Masciandaro, Macci, Peruzzi, Ceccanti & Don, 2013). This growth may occur rapidly, as soil microbial biomass doubled from 2 to 4 $\mu g\ g^{-1}$ in 7 weeks in soils growing galega, which corresponded with increased enzymatic activities (Mikkonnen et al., 2011). Similarly, microbial biomass in soils growing alfalfa (Hamdiet al., 2012) and wheat (Shahsavari, Adetutu, Taha & Ball, 2015) increased by several orders of magnitude (CFU g^{-1} soil). Interestingly, the community composition did not shift to favor TPH degraders in either case, indicating that the numbers already present in the soil were sufficient for contaminant degradation.

The accumulation of incomplete metabolites of PHC degradation has been shown to harm vegetation and soil macrofauna, but soil microbial communities do not appear to be as sensitive. Compost application to PHC-contaminated soil in a laboratory incubation resulted in a 400% increase in basal respiration and a 200% increase in phosphatase and betaglucosidase enzyme activities (Bastida, Jehmlich, Lima, Morris, Richnow & Hernandez, 2016). Similarly, heterotrophic bacteria increased up to 200% in land farm soil fertilized with N, P, and K compared to the control (Besalatpour, Hajabbasi, Khoshgoftarmanesh & Dorostkar, 2011). In conjunction with increased respiration and biomass, the Shannon index of microbial community diversity increased from 1.4 to 3.6 in a land farm soil with organic amendments (Wang et al., 2016). The inundation of resources from composting, aeration, irrigation, and fertilization greatly increases soil microbial abundance and diversity, despite increased toxicity levels

Recent studies have been able to tie these broad microbial metrics to specific shifts in microbial community composition. In a comparison of methods, the primary hydrocarbon degraders in biopiles were Alpha-proteobacteria, whereas bioslurry treatments were dominated by Gammaproteobacteria (Smith, Thavamani, Ramadass, Naidu, Srivastava & Meghara, 2015). A laboratory incubation study found another distinction in microbial communities, wherein oil-contaminated soil with added compost contained 50% more gram-positive bacteria, while gram-negative bacteria were more prevalent in non-compost soils (Bastida, Jehmlich, Lima, Morris, Richnow & Hernandez, 2016) These shifts show the dominance of organisms that thrive in more extreme environments (e.g., gram-positive bacteria), but the impacts on soil functions are unclear. Perhaps future advances in these techniques can elucidate the impacts of these community shifts, but in these studies, no clear indication of inhibition of soil waste management or nutrient cycling was identified.

In addition to these biological implications, bioremediation also changes the hydrologic functioning of the soil, especially in methods with compost amendments. The application of SOC improves water-stable aggregation and porosity (Regelink, Stoof, Rousseva, Weng, Lair & Kram, 2015), thereby increasing water holding capacity and infiltration, as well as decreasing erosion. Thus, composting encourages both soil fauna and vegetation by allowing greater access to both water and essential nutrients. However, very high concentrations can harm water quality, as compost application at 5% w/ w increased water-soluble carbon from 12 to 33 mg kg^{-1} (Bastida et al., 2016) similar increases in other nutrients could exceed the soil's ability to filter and protect water resources.

Environmental Impact of Phytoremediation

Due to the synergy of plants, soils, and microorganisms, soil function is generally improved during treatment, although few studies offer a direct comparison to non-contaminated soils. Notably, many of these studies utilized phytoremediation either as a secondary treatment or as a strategy for low amounts of contamination. Thus, declines in plant growth or increased toxicity to organisms were attributed to conditions caused by soil properties (e.g., high electrical conductivity (EC), low pH) rather than contamination. However, in sites where contamination was likely the cause for reduced plant production, contaminant reduction resulted in greater biomass production (Mikkonnen et al., 2011; Shahsavari et al., 2015), indicating that these soils 'suitability for vegetation was increased by phytoremediation. Thus, increased vegetative production improves soil properties, which improves contaminant reduction, which improves vegetation production; this positive cycle typifies a successful phytoremediation project

The increased porosity and aggregate stability accompanying root growth improve soil structure to allow for better transport of water, oxygen, and nutrients for soil organisms and root uptake. This access to resources is a primary cause of the increase in soil microorganism populations, and it does not seem to be accompanied by a shift in community composition (Shahsavari et al., 2015). Therefore, typical nutrient cycling and organic compound degradation may be expected to continue in these soils. Further, the presence of roots, in conjunction with an overall increase in SOM, serves to intercept nutrients from the soil solution, reducing losses associated with leaching.

Nonetheless, a primary concern for phytoremediation strategies, as with any in situ treatment, is the migration of contaminants in the soil profile, as treatment may take several months or years. The propensity of a contaminant to migrate is widely variable, as it is based on its characteristics, especially solubility, cohesion, and adhesion, as well as the soil characteristics, especially moisture content, texture, and SOM (Rivett, Wealthall, Dearden &, McAlary, 2011). For example, fuel compound mobility was low when applied to pure montmorillonite or topsoil, but the addition of some root exudates to both increased contaminant mobility (Balseiro-Romero, Kidd & Monterroso, 2014). These responses may have been based on the effect of root exudates on soil pH, wherein carboxylic compounds decreased pH and increased mobility whereas phenolic compounds increased pH and reduced mobility.

Complexities and the Challenges in Phytoremediation

Although phytoremediation is becoming increasingly popular for cleaning-up of contaminated soils, many challenges related to the site-specific condition, nature of pollutants, timeline, and efficiency have not been overcome yet. Many of the polluted sites contain a heterogeneous and complex mixture of thousands of compounds with broad Physico-chemical characteristics, toxicity, and availability levels. Contaminated sites pose technical challenges associated with the nature of pollutants plus the new problems that arise due to the presence of two (or many) classes of contaminants with different properties (Chirakkara et al. 2016). The presence of both organic and inorganic compounds increases interaction effects that could lead to an increase or decrease the efficiency of remediation technology. The presence of organic contaminants may positively or negatively affect the transport and removal of trace elements in soils while the inherent toxicity of trace elements can inhibit the biodegradation of organic contaminants by the microorganisms in the soil (Chirakkara et al. 2016). Degradation of pollutant mixture has been considered in many investigations where researchers used the phytoremediation technique to treat pollutant-spiked soils (Wei and Pan 2010; Peng et al. 2009). However, by contrast to freshly contaminated soil, the remediation of PHC that has been present in the soil for ages is still difficult since they are less available.

Thus, very little is known about the plant metabolism pathways involved in the degradation and toxicity of these compounds (Chigbo & Batty, 2013). In addition to the challenges related to the use of aged co-contaminated soils in this study and the complexity of these pollutants, soil characteristics bring another level of complexity that has to be solved. In crude oil-contaminated sites, the carbon (C): nitrogen (N) and phosphorus (P) ratios become imbalanced due to the high input of C into the system, leading to N and P immobilization or depletion through microbial activity (Adam & Duncan, 2002). Current research in phytoremediation is often requiring a high input of N into the soil to significantly reduce pollutant concentration. Investigation of the degradation of crude oil by using plants adapted for nutrient acquisition (nitrogen fixation for instance) is beneficial to sustain phytoremediation.

Choosing plant species and varieties for phytoremediation is also challenging because the introduction of non-native or genetically modified plants into the environment could be an issue (Hakeem et al. 2015). Furthermore, phytoremediation is a site-specific process and feasibility studies are required before full-scale remediation can be applied successfully. Preliminary studies on a laboratory scale can be used to predict degradation rates but it does not reflect field conditions, therefore we should use phytoremediation as a multi-scale perspective. Finally, it is important to complement and integrate phytoremediation studies with ecotoxicological analysis taking into account the effect of bioavailable contaminants and their interaction.

CONCLUSIONS

This review identified and summarized important impacts phytoremediation on soil properties. Notably, phytoremediation affected soil pH and SOM, which are important soil parameters that regulate many ecological processes. Nonetheless, these parameters by themselves are insufficient for describing changes to soil function caused by remediation techniques, as soil processes must be understood as complex, dynamic relationships between all soil properties. The magnitude of the effects on soil function is determined by the type of application and treatment parameters (e.g., the dosage of oxidant, the temperature of TD).

Based on this review, there is an accession for phytoremediation studies in crude oil-polluted soil and also to plant it in crude oil polluted soils instead of leaving such soils fallow. This will help to eliminate wastage of such polluted sites, provide cover to the polluted site as to reduce contact and ingestion of the polluted soil by children will be minimized and to get other values of the crop apart from its widely publicized nutritional values. Therefore, it is recommended that if any plant is found to be a good phytoremediation of crude oil polluted site, it can be used to clean up soil polluted with crude oil. This will add to the already known uses of the plant.

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