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Assessing the Effect of Bioremediation Agent Made from Local Resource Materials in Nigeria on Soil pH

[1]Adebola A. Adekunle, [2]Iheoma M. Adekunle and [1]Tobit O.

[1]Department of Civil Engineering, College of Engineering,
University of Agriculture, Abeokuta, Ogun State, Nigeria
[2]Department of Chemistry, Faculty of Science,
Federal University, Otuoke, Bayelsa State, Nigeria.

Corresponding Author: Iheoma M. Adekunle

Abstract

Remediation of oil polluted soils of the Niger Delta region of Nigeria is a burning environmental issues in the country. As a contribution to the promotion of local content policy to solving the problem, a bioremediation agent (Ecorem) that provides excellent destruction of hydrocarbons in soil was formulated from local raw materials. This study was aimed at assessing the impact of the formulation on soil pH as a part study on its effect on soil properties to establish eco-toxicological significance of product. Influence of product-soil weight ratio on soil pH was examined and predictive equations were developed. Result showed that remediation with Ecorem increased soil pH by 3.27 to 9.71%, improved the original soil status (6.25 ± 0.01) by 2.72 to 12% without rendering the treated soil acidic or alkaline. The effect also varied with Ecorem – soil weight ratio, giving positive correlations with coefficients of up to 0.865($p = 0.06$), which is a function of petroleum product type. Predictive equations developed showed that for planning remediation project execution using Ecorem; for soil contaminated by petroleum products such as spent engine oil and crude oil, marginal negative errors of 2 to 6% and positive error of 1 to 2% on pH value should be taken into consideration.

Keywords: environment, Nigeria, petroleum bioremediation, raw material development, soil pH

INTRODUCTION

The exploration, exploitation and production of petroleum resources inevitably release oil into the environment via operational, intentional and accidental spills of crude oil and refined petroleum products (Kingston, 2002; Burgherr, 2006). The resultant contamination of soils, ground water, surface water, sediments, swamps, vegetation and air with hydrocarbon compounds contained in spilled petroleum products is a major environmental challenge in oil producing communities, especially the Niger Delta region of Nigeria (Osuji, 2006; Osuji, 2010; UNEP, 2011). The environmental hazards resulting from oil spill into the environment include adverse alteration of soil quality, soil fertility, plant physiology and water quality (Kingston, 2002; Andrade et al., 2004). All these ultimately result in damaged ecosystem, poor farm harvest, poverty, hunger and degenerated animal and human health.

Recently, there are more agitations to clean up, reclaim and restore all oil impacted environments in the Niger Delta (UNEP, 2011). Reclamation of these affected areas begins with recovery of free phase oil, treatment of residual hydrocarbons in soil and water and certification exercise by appointed regulatory bodies. Until a couple of years ago, techniques adopted for the remediation of oil impacted environments include physical, chemical and thermal solutions. Each of these three methods has inherent environmental issues resulting in the search for more environmentally friendly approaches. Biologically based treatments subsequently evolved and gained a much more public acceptance due to their closeness to nature (Vidali, 2001; Gogoi et al., 2003; Benyahia et al., 2005; Bello, 2007).

A remediation effort suitable under a given climate and condition may not necessarily be adequate in another setting. The need to reclaim, remediate and restore these contaminated environments to their original utility purposes and functionality has led to the development of bioremediation formula, suitable for the destruction of the hydrocarbon compounds without compromising environmental quality. Field survey revealed that the use of locally resourced materials to treat and dispose of these hydrocarbon-contaminated wastes from petroleum industries has high acceptance by stakeholders in the country (Adekunle et al., 2012), supporting previous demonstrations on the possibility of harnessing and transforming some readily accessible local resources in the country to products useful in the treatment of soils impacted by petroleum products (Adekunle, 2010; Adekunle et al., 2011; Adekunle, 2011). Building on this concept, a bioremediation product (Ecorem), was formulated from local resource materials found in Nigeria. This product is designed to address multiphasic, heterogenous complexities in contaminated environment in the Niger Delta and provide excellent degradation of hydrocarbon compounds in environmental matrices such as soils and drill mud and cuttings. As a step to assessing the environmental impact of Ecorem, its influence on soil properties has to be considered to establish eco-toxicological significance. Soil pH is an important factor that controls the availability and mobility of elemental contents in the soil, especially heavy metals due to its influence on sorption/desorption, precipitation/ dissolution, complex formation and oxidation-reduction reactions (Spurgeon et al., 2006; Wang et al., 2006)). Consequently, this study was designed to assess (i) the effect of petroleum product spill on soil pH (ii) the impact of remediation using indigenous product on the soil pH in comparison to soil original status and the remediated matrix (iii) influence of product-soil ratio on soil pH and (iv) simulation of product-soil ratio on soil pH for predictive purposes.

MATERIALS AND METHODS

Description of Bioremediation Formulation

Natural organic waste materials (plants and animal wastes), sourced from Nigeria, were formulated via composting technology. The basics of the composting procedure were described in the reports of (Adekunle, 2010; Adekunle et al., 2011; Adekunle, 2011). The composted wastes were then modified with some naturally occurring, biodegradable materials, also locally sourced to give a technical producted denoted as "Ecorem".

Soil Contamination with Petroleum Products

About 60Kg bulk soil sample was collected from a remote area within the campus of the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria. The bulk was air dried, sieved through 2 mm mesh, analyzed for some basic soil properties; organic matter, cation exchange capacity, pH, temperature and particle size distribution, as described in (Page et al., 1982). The bulk soil sample was then transferred to different 4L capacity plastic pots at 3 Kg per pot. The content in each pot was homogenized by mechanical stirring using a wooden device. Crude oil (CDO) was transferred into a separating funnel to isolate the aqueous phase from the black organic phase. Spent engine oil (SEO), obtained from one of the auto repair workshops in Abeokuta was also passed through the separating funnel for the same purpose. The 3 Kg soil in each pot was contaminated with either CDO or SEO at 6.67% (v/w) and agitated thoroughly for homogenization using a wooden device and allowed to stabilize for 21 days in a screen house.

Treatment of Contaminated Soil using Ecorem

In a screen house environment, Ecorem was utilized to treat soils contaminated with two petroleum products namely crude oil and spent engine oil. Soils were assessed for initial concentration of total petroleum hydrocarbon before the application of bioremediation agent (Ecorem) , using the method described by Adekunle (2011). This analysis was repeated at the end of the remediation period. Ecorem was then applied to the soils contaminated with two petroleum products. The different system designs for the crude oil and spent engine oil contaminated series are presented in Table 1 and the pots were placed in a completely randomized block design.

Table 1: Different system designs for the crude oil and spent engine oil contaminated series in the experimental set-up

S/N	System description for spent engine oil (SEO) series	System code	System description for crude oil (CDO) series	System code
1.	Soil without SEO contamination and treatment	Soil (S)	Soil without CDO contamination and treatment	Soil (S)
2.	Soil contaminated with SEO and received no treatment.	S + SEO	Soil contaminated with CDO and received no treatment	S+CDO
3.	Soil contaminated with SEO and treated with Ecorem	S+SEO+Ecorem-675g	Soil contaminated with CDO and and treated with Ecorem	S+CDO+ Ecorem - 675g
4.	Soil contaminated with SEO and and treated with Ecorem	S+SEO+ Ecorem-810g	Soil contaminated with CDO and treated and treated with Ecorem	S+CDO+ Ecorem - 810g
5.	Soil contaminated with SEO and and treated with Ecorem	S+SEO+ Ecorem -945g	Soil contaminated with CDO and treated by compost bioremediation	S+SEO+ Ecorem - 945g
6.	Soil contaminated with SEO and and treated with Ecorem	S+SEO+ Ecorem -1080g	Soil contaminated with CDO and and treated with Ecorem	S+CDO+ Ecorem-1080g
7.	Soil contaminated with SEO and and treated with Ecorem	S+SEO+ Ecorem -1215g	Soil contaminated with CDO and treated and treated with Ecorem	S+CDO+ Ecorem-1215g

The experiment had two controls: (i) soil without SEO/CDO contamination and treatment and (ii) soil contaminated with fuel oil (SEO or CDO) and received no treatment. The different Ecorem-soil ratios (w/w) were 23%, 27%, 31.5%, 36% and 41% and each pot system was replicated four times. The introduction of Ecorem into each pot, was followed by homogenization process and watering to provide aeration and moisture respectively. Aeration was thereafter enhanced on weekly basis. No other form of nutrient supplement or amendment was introduced into the system throughout the remediation period of 33 days.

Assessment of Soil pH

Soil pH was assessed in soils before contamination with petroleum product, immediately after soil contamination with the oil products and soils contaminated with oil products but remediated with Ecorem as described in Table 1. Soil sample collection from each pot was carried out as follows: a grid template was created on the surface and about 2g soil was collected from the different grid segments, mixed thoroughly to form a composite, air dried and then sieved through a 2mm sieve. Exactly 10g portion of the composite was weighed into a 100 mL sample bottle and a 1: 5 soil-water suspension was prepared by the addition of 50 mL of deionized water procured from the International Institute of Training and Research (IITA), Ibadan, Nigeria. The soil-water suspension was agitated on Edmund Buhler shaker at 200 rpm for 60 minutes, centrifuged at 350 rpm for 5 minutes. The pH meter was calibrated according to manufacturer's instruction, using buffer solutions of pH values 4.0 and 10.0. The value displayed on the meter was then recorded.

Prediction of Soil pH During Bioremediation using Ecorem

Primary data generated from the experiment were used to obtain general linear regression models for SEO and CDO series. From the mathematical models, % Ecorem-soil weight ratio: 1, 5, 10, 15, 20, 23, 25, 27, 30, 31.5, 35, 36, 40, 41, 45, 50 and 60 were utilized as independent variables. The values predicted for % Ecorem-soil weight ratios 23. 27. 31.5. 36 and 41 were compared with the actual values of soil pH obtained during the study.

Statistical Analysis

Data generated from the study were subjected to statistical analysis using SPSS 16.0 for Windows® to compute descriptive statistics in order to obtain means and standard deviations. Analysis of variance was used to compare means from different treatments for significant variation and Pearson correlation was applied to assess the relationship between the Ecorem-soil weight ratios and soil pH values.

RESULTS AND DISCUSSIONS

Results

Soil properties and hydrocarbon degradation

Results on basic properties and reduction in total petroleum hydrocarbons for soil used in this study are presented in Table 1. The soil used in this study was characterized as sandy due to its particle size distribution.

Table 1: Basic soil properties and reduction in total petroleum hydrocarbons

S/N	Soil property	Mean value	Standard deviation
1.	Cation exchange capacity ($cMolKg^{-1}$)	1.42	0.01
2.	Organic matter (%)	3.45	0.61
3.	Silt (%)	7.40	0.70
4.	Sand (%)	91.2	1.6
5.	Clay (%)	1.40	0.10
6.	pH	6.25	0.05
Reduction in total petroleum hydrocarbon = 99%			

Effect of Oil Pollution on Soil pH

The pH of the soil before contamination with petroleum products (CDO and SEO) and soils contaminated with petroleum products are presented in Fig.1. The mean value of soil pH before contamination with either CDO or SEO was 6.25±0.05. The introduction of SEO raised the value to 6.40±0.03, corresponding to a 2.4% increase. Contamination of the soil with CDO gave a 1.76% increase, raising the mean pH values from 6.25 ±0.05 to 6.36±0.12.

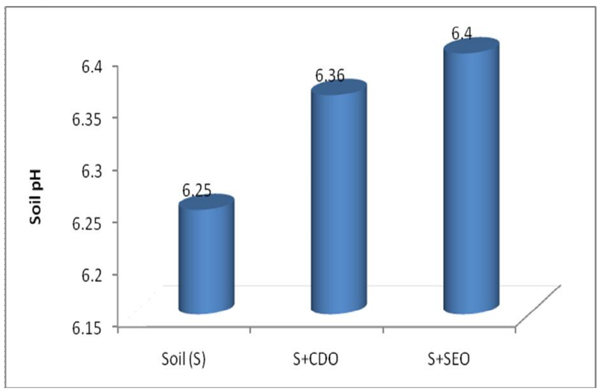

Fig.1: pH value for uncontaminated soil and those contaminated with petroleum products

Impact of Ecorem application on soil pH value

Absolute Effect on Soil pH

The values for soil pH immediately after contamination with petroleum product and after Ecorem treatment and the effect of this treatment for soils contaminated by spent engine oil and crude oil are presented in Table 2. Results showed that the application of Ecorem to crude oil impacted soil affected soil pH status. The initial values for soils impacted by crude oil (immediately after spill) ranged from 6.28 to 6.47 but after remediation the values varied from 6.75 to 7.00. By these, the soil pH values were increased by 4.33 to 9.71% due to treatment with Ecorem. Similarly, the remediation of soils impacted by spent engine oil increased the soil pH values. Before Ecorem application, the values ranged from 6.30 to 6.45 and after the treatment, it varied from 6.63 to 6.95, corresponding to increases by 3.27 to 7.75%. However, in one instance, a reduction by 0.16% (from 6.43 ±0.09 to 6.42±0.27) was recorded.

Table 2: Soil pH immediately after soil oil contamination, after remediation and treatment impact

S/N	System code	Soil pH before remediation	Soil pH after remediation	% Effect of Ecorem treatment on soil pH
Crude oil (CDO) series				
1.	Soil + CDO +Ecorem-675g	6.28±0.12	6.78±0.17	7.96
2.	Soil + CDO + Ecorem-810g	6.38±0.03	6.85±0.09	7.37
3.	Soil + CDO+ Ecorem -945g	6.47±0.10	6.75±0.09	4.33
4.	Soil + CDO + Ecorem -1080g	6.31±0.20	6.80±0.24	7.77
5.	Soil + CDO + Ecorem -1215g	6.38±0.18	7.00±0.19	9.71
Spent engine oil series				
6.	Soil + SEO + Ecorem-675g	6.43 ±0.09	6.42±0.27	-0.16
7.	Soil + SEO + Ecorem-810g	6.30± 0.18	6.66±0.13	5.71
8.	Soil + SEO + Ecorem-945g	6.41±0.09	6.67±0.27	4.06
9.	Soil + SEO + Ecorem-1080g	6.42±0.17	6.63±0.11	3.27
10.	Soil + SEO + Ecorem-1215g	6.45±0.03	6.95±0.23	7.75

Negative sign stands for decrease, for each mean value, n = 4

Effect Relative to Original and Contaminated Soil pH Values

Results presented in Fig.2, showed that the utilization of Ecorem for the remediation of soils contaminated with spent engine oil generally increased soil pH in the range of 6.42 to 6.95. These values exceeded the uncontaminated soil by 2.72 to 11.20% and contaminated soils that received no Ecorem supplement were exceeded by 0.31 to 8.59%. The impacts of bioremediation using Ecorem on crude oil impacted soils are presented in Fig.3. Results showed that the utilization of the bioremediation agent increased the soil pH value in the range of 6.75 to 7.00 compared to the original value of 6.25. These values exceeded the uncontaminated soil by 8.00 to 12% and contaminated soil that received no Ecorem supplement by 6.13 to 10.06%.

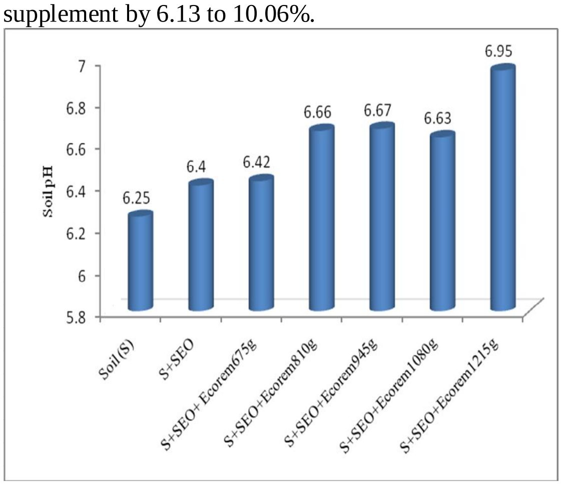

Fig.2: pH values for uncontaminated soil, contaminated soil and soils contaminated with spent engine oil but treated with Ecorem for 33 days

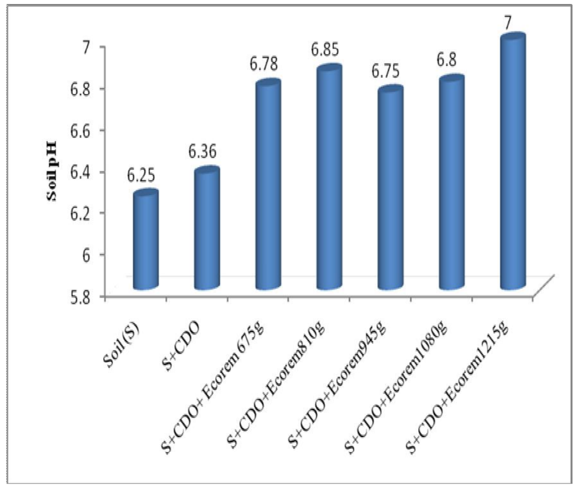

Fig.3: pH values for uncontaminated soil, contaminated soil and soils contaminated with crude oil but treated with Ecorem for 33 days

Soil pH values in these soil systems were positively impacted by Ecorem-soil weight ratios as shown in Figs.4 and 5. For SEO series (Fig.4), data from linear regression showed that the change in soil pH per 1% (w/w) of Ecorem to soil ratio was 0.022. A positive correlation with a coefficient (r) of 0.865; p = 0.06, was obtained within a Ecorem- soil weight ratio range of 23 to 41% (w/w).

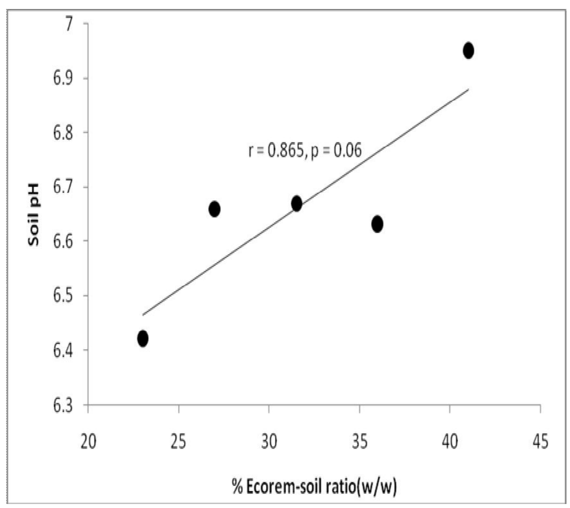

Fig.4: Relationship between soil pH and the dose of Ecorem applied during remediation to soils contaminated with spent engine oil

Soil pH values (for crude oil series) were also positively impacted by Ecorem-soil weight ratio as shown in Fig.5. Linear regression showed that the change in soil pH per 1% (w/w) of Ecorem-soil ratio was 0.008; positive correlation with a coefficient (r) of 0.643; p= 0.259, was obtained within percentage weight ratios of 23 to 41%.

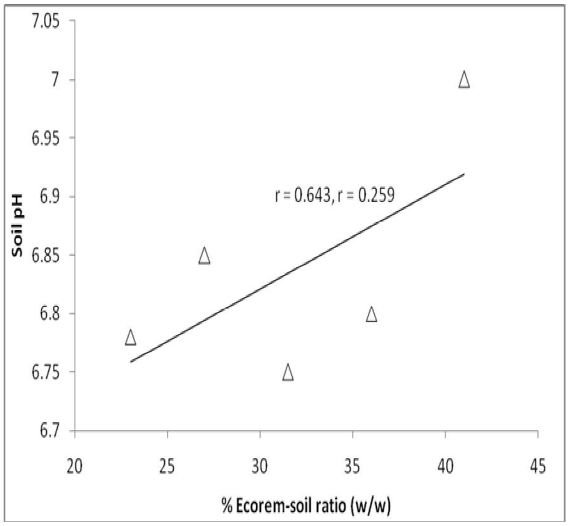

Fig.5: Relationship between soil pH values and the dose of Ecorem applied during remediation to crude oil contaminated soil

Predicting Impact of Ecorem on Soil pH During Bioremediation

Linear models developed for the prediction of the impact of Ecorem on soil pH values during bioremediation are given as the prediction models (i) and (ii) for soils contaminated by spent engine oil and crude oil respectively:

$$P_{(pH)} = 0.022\, f_{Ecorem} + 5.954 \ \dots \text{(i)}$$
$$P_{(pH)} = 0.008\, f_{Ecorem} + 6.553 \ \dots \text{(ii)}$$

where $P_{(pH)}$ is the predicted soil pH and f_{Ecorem} stands for percentage Ecorem-soil ratio (w/w). The soil pH values generated by the prediction models and the actual values obtained during the study are compared in Figs.6 and 7. Results showed that for the remediated spent engine oil impacted soil systems (Fig.6), at f_{Ecorem} 27, 31.5, and 41, the respective predicted and actual pH values were 6.55: 6.66, 6.65:6.67 and 6.86 ; 6.95. These results showed that the predicted pH values were less than the actual pH values by 1.67%, 0.30% and 1.31% respectively. However, at f_{Ecorem} 23 and 36, the respective predicted and actual pH values were 6.46:6.43 and 6.75:6.63, showing that the predicted pH values exceeded the actual pH values by 0.47% and 1.80% respectively. In the case of remediated crude oil impacted soil systems (Fig.7), at f_{Ecorem} 23, 27 and 41; the respective predicted and actual pH values were 6.74:6.78, 6.77:6.85 and 6.88:7.00. These reveal the fact that the predicted values were less than the actual pH values by 5.93%, 1.18% and 1.74% respectively. On the contrary, at f_{Ecorem} 31.5 and 36, the respective predicted and actual pH values were 6.81:6.75 and 6.84:6.80; showing that the predicted pH values exceeded the actual pH values by 0.89% and 0.59% respectively.

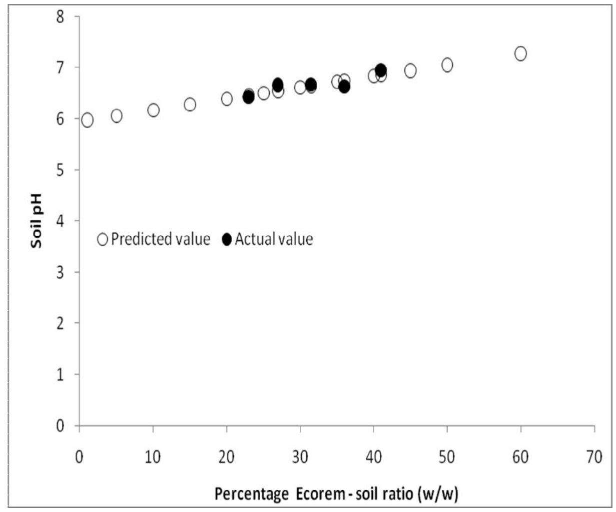

Fig.6: Comparison between predicted and actual soil pH values on application of bioremediation using Ecorem for soils contaminated with spent engine oil

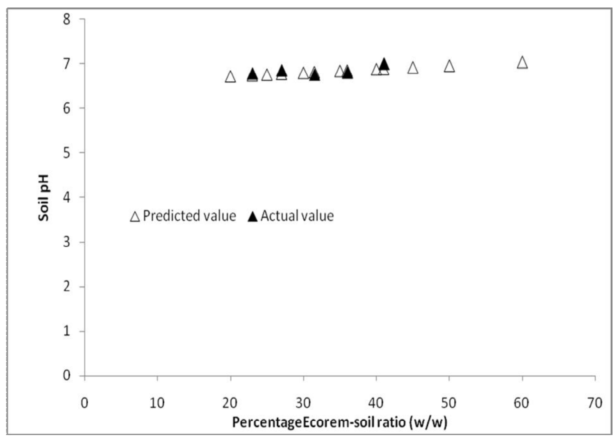

Fig.7: Comparison between predicted and actual soil pH values on application of bioremediation using Ecorem for soils contaminated with crude oil

DISCUSSION

The pH value of a soil indicates the level of its acidity or alkalinity. Classification of soil based on pH value is as follows: ultra acid for < 3.5, extreme acid for 3.5 – 4.4, very strong acid for 4.5 – 5.0, strong acid for 5.1 – 5.5, moderate acid for 5.6 – 6.0, slight acid for 6.1 - 6.5, neutral for 6.6 – 7.3, slightly alkaline for 7.4 -7.8, moderately alkaline for 7.9 – 8.4, strongly alkaline for 7.9 – 8.4 strongly alkaline for 8.5 - 9.0 (SSDS, 1993; Wikipedia, 2012). Accordingly, data from this study revealed that before oil contamination, the soil (pH of 6.25) was slightly acidic. Contamination with either crude oil or spent engine oil still left the soil slightly acidic but treatment with Ecorem transformed the soil from slightly acidic to the neutral range.

Results from this study also revealed that soil pH after remediation did not fall outside of the general range of 4.0 to 8.0 found in Nigerian soils. The optimum pH range for most plants is between 6 and 7.5, however many plants have adapted to thrive at pH values outside this range. Results from this study showed that treatment of the oil contaminated soils did not raise the pH values outside of this agriculturally useful range. Some agricultural soils in Nigeria are characterized by low pH. For instance, the pH values of seven agricultural sites in Kaduna were characterized by pH range of 4.68 to 5.38. In the southeast, it was reported as 4.50 to 5.64 and 6.3 to 7.1 in the southern Guinea savanna zone. High rainfall areas such as the south-south and south-eastern regions in Nigeria, especially the Niger Delta (oil bearing region), are reputed for low pH due to leaching events, therefore, remediation of oil impacted soils using Ecorem would raise soil pH values and render them more agriculturally viable and boost food security (Akporhono and Agbaire, 2009; Olabiyi et al., 2009; Ibiremo et al., 2010; Mohammed and Ayodele, 2011). One of the major advantages of Ecorem product is that it would help raise the pH of soils in regions characterized by low pH value to values suitable for viable agriculture, which is the major land use in the country.

Regarding the influence of Ecorem-soil ratio on soil pH values, results revealed positive relationships, indicating increased soil pH with increasing Ecorem load during the remediation. In the treatment of soils contaminated by crude oil and refined petroleum products, it is necessary to have knowledge on the implication of a selected treatment technique on the soil pH to allow decisions for further remedial measures because pH values outside of the optimum range for agriculture (6.5 – 7.5) is not desirable. Predictive equations developed in this study have proved that even at the maximum Ecorem-soil ratio of 60%, the product would not render the treated soil alkaline as the maximum predicted pH value for treated soils was 7.00. If the application raises the soil pH to a strongly alkaline range, uptake of nutrients by plants may be suppressed; hence it would be needful to restore the soil pH. Research is currently ongoing to develop natural products that could modify soil pH to the desired range.

The simulation models generated in this study will provide important guide, in relation to soil pH values for the planning of remediation works using Ecorem. For instance, results showed that for the remediation of soils impacted by spent engine oil the predicted pH values could fall below the actual value by 0.30 to 1.67% or exceed by 0.47 to 1.81%. In the case of soils contaminated by crude oil, the predicted soil pH value could fall below the actual value by 1.18 to 5.93% or exceed by 0.59 to 0.893%. It is suggested that the maximum error values be utilized for prediction purposes. This implies that while planning for the percentage Ecorem-soil weight ratios to be utilized in the remediation of soils contaminated by spent engine oil, a marginal negative error of 1.67% and a marginal positive error of 1.81%. For the remediation of crude oil contaminated soils, the errors are much more reduced: a marginal negative error of 5.93% and positive error of 1% should be taken into consideration.

CONCLUSIONS

Based on the findings from this study, it is concluded that (i) soil contamination with either crude oil or spent engine oil left the soil in the acidic region, (ii) the application of bioremediation agent made from local resource materials from Nigeria restored the soil pH to the agriculturally useful range, (iii) positive correlations were obtained between soil pH and Ecorem-soil weight ratios and (iv) useful simulation models for soil pH predictive purposes for the planning a bioremediation project using the product were generated. There was no obvious study limitation but the next stage in this study is the crystallization of technology for active remediation project.

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