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Original Report

ASSESSING AND FORECASTING THE IMPACT OF BIOREMEDIATION PRODUCT DERIVED FROM NIGERIA LOCAL RAW MATERIALS ON ELECTRICAL CONDUCTIVITY OF SOILS CONTAMINATED WITH PETROLEUM PRODUCTS

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Abstract: As a contribution to the promotion of local content policy in the study of petroleum and environment in Nigeria, a bioremediation agent (Ecorem) was formulated from local raw materials. Process kinetics to study operation mechanism of the product was subsequently embarked upon. This study was aimed at assessing the impact of the formulation on soil electrical conductivity (SEC) as a part study on its effect on soil properties. Influence of product-soil weight ratio on SEC was examined and predictive equations were developed. Result showed that Ecorem increased SEC by 13.43 to 23.03%, improved the original soil status (159.25 ±9.25 μScm^{-1}) by 8.63 to 52.94% and did not render the treated soil saline. The effect also varied with Ecorem – soil weight ratio, giving positive correlations with coefficients of up to 0.967 ($p = 0.01$); 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 9% and positive error of 2 to 17% should be taken into consideration.

Keywords: Environment, Nigeria, petroleum bioremediation, raw material development, soil property

INTRODUCTION

The economy of Nigeria, no doubt, anchors on petroleum resources but in spite of the blessings from oil, there are obvious negative impacts on the human and ecological environment.

The worst hit in the oil related environmental issues are the oil bearing communities, located in the Niger Delta region of the country, which currently comprises of up to nine states (Bayelsa, Delta, Rivers, Abia, Akwa-Ibom, Cross River, Edo, Imo and Ondo) out of the 36 states of the country. The frequent oil spills in the country often result from industrial operational failure, accidental discharge, illegal oil refining and pipeline vandalization. Delays in the reclamation of oil impacted surfaces, irrespective of the cause of spills, often result in conflicts capable of disrupting national security. The resolution of these oil related conflicts would be more rapidly achieved if in addition to payment of compensations to the affected communities, their degenerated and degraded environments are restored to original functionality as suggested in the report compiled by United Nations Environmental Programme [1].

Land use and functionality vary from one country to the other and from one local region to another. Land use factor should form a critical decision making index in the choice of remedial platform, for the treatment of soils impacted by petroleum products. The major land use in the oil bearing communities of Nigeria is agriculture [1], hence a needful remediation efforts on oil impacted land areas in the country should be geared towards the restoration of land to arable status. Remediation by chemical and thermal technologies does not encourage the usage of the remediated soil for agriculture. Bioremediation technologies are globally preferred to chemical and thermal method of treating oil impacted soils due to their environmentally friendly characteristics. Of the bioremediation technologies (biosparging, phytoremediation, bioventing, bioreactor design, land farming, use of engineered microorganisms etc), compost based techniques appear to be more suitable for the Nigeria situation because when properly implemented, it transforms the contaminated land to arable farms. Remediation by compost based technology anchors on the use of natural biodegradable materials to facilitate the process of nutrient release into soil, augmentation and stimulation of microorganisms [2-8].

The efficiency of a given remediation by composting technology or compost based technique is a function of a wide variety of factors such as geographical location, product formulation, feedstock for product formulation, nature and properties of formulated products, method of application, contaminant type, degree and complexity of matrix contamination, human expertise and remediation target levels. These basic success factors vary from one part of the globe to another. Conventional remediation by composting technology, almost like natural attenuation (reliance on indigenous microorganism present in the contaminated surfaces, to remediate contaminants, especially petroleum products), takes a long time ranging from one to five years to achieve desired remediation targets. The level of contaminants required prior to close out of a remediation project (remediation target) and compliance to set regulatory standards, differ from one country to another.

Composting or compost based method as an environmental remediation technology is still at the research platform in Nigeria; the focus being on the remediation of soil contaminated with heavy metals [9, 10] and those impacted by petroleum products [11,12]. The impact of bioremediation by composting technology to soil quality is case specific, depending on the type of feedstock, applied technique, type of contaminant and nature of contaminated material to be treated. Accordingly, there is still the need for concerted studies and investigations to boost the data base on this technology globally and Nigeria in particular.

As a follow-up to the previous investigations on need based research and development studies, aimed at the development of viable bioremediation products from local raw materials found in Nigeria for bioremediation of oil polluted environmental matrices [13, 14, 15], a study on process kinetics of the technology was conducted. The study was designed to give more insight and knowledge on the use of compost based technology derived from organic feedstock from

Nigeria, in the remediation of soils and other materials such as drilling mud and cuttings impacted by petroleum products. The focus was on assessing the impact of the technology on key soil properties (electrical conductivity, pH, moisture content, heavy metal concentrations, microbial community, ability to sustain plant life and temperature) that have bearing on fertility and crop production.

This present report is on soil electrical conductivity, which is a measure of ions in soil aqueous phase, indicating the amount of soluble ions in soil. It's importance lies in the correlation with soil properties that affect agriculture and environmental issues; it influences factors that affect crop productivity (soil texture, cation exchange capacity, organic matter and salinity levels) and to soil engineering practices such as salinity, subsoil characteristics and drainage conditions [16]. Hence, the objectives of this work were to examine the (i) effect of petroleum product spill on soil electrical conductivity (ii) impact of remediation using the compost based product on the soil electrical conductivity relative to soil original status and the remediated matrix (iii) influence of product-soil ratio on soil electrical conductivity and (iv) simulation of product-soil ratio on soil electrical conductivity 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 [12,13,14]. 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, with no obvious petroleum contamination, within the campus of the Federal University of Agriculture, Abeokuta, Ogun State, Nigeria. The bulk soil 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 [17]. 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.

Soil bioremediation by using Ecorem

The bioremediation study was conducted under screen house conditions. Soils were assessed for initial concentration of total petroleum hydrocarbon before the application of bioremediation agent (Ecorem). 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.

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.

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

Assessment of soil electrical conductivity

Soil electrical conductivity was assessed in soils before contamination with petroleum product, immediately after soil contamination with the oil products, 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 conductivity meter was calibrated according to manufacturer's instruction and the value displayed on the meter was then recorded.

Prediction of soil electrical conductivity 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 electrical conductivities 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 the soil property.

RESULTS AND DISCUSSION

Soil properties and hydrocarbon degradation

The soil used in this study was characterized by mean pH of 6.01± 0.12, cation exchange capacity of 1.42 ±0.01 $cMolKg^{-1}$, organic matter content of 3.45±0.61%, silt, sand and clay contents of 7.4 ±0.7%, 91.2± 1.6% and 1.4± 0.1% respectively. Based on the particle size distribution the soil was classified as sandy. The product provided up to 99% destruction of total petroleum hydrocarbons.

Effect oil pollution on soil electrical conductivity

The electrical conductivities of uncontaminated soils and soils contaminated with petroleum products (CDO and SEO) are presented in Fig.1. The electrical conductivity before contamination either by CDO or SEO was 159.25 ±9.25 μScm^{-1}. The introduction of SEO reduced the value to 151.83 ±9.88 μScm^{-1}, corresponding to 4.88% decrease. Contamination of the soil with CDO gave 4.31% decrease, reducing the electrical conductivity value from 159.25 ±9.25 μScm^{-1} to 152.67 ±22 μScm^{-1}.

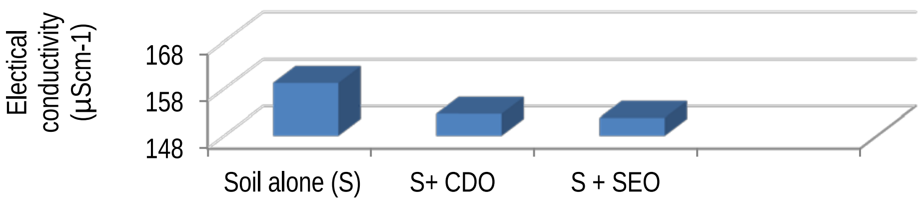

Fig.1: Electrical conductivities for uncontaminated soil and those contaminated with petroleum products

Impact of Ecorem application on soil electrical conductivity

Absolute effect on electrical conductivity: The values for electrical conductivity 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 positively influenced soil electrical conductivities. The values on contamination with crude oil ranged from 151.75 to 160.50 µScm-1 but after remediation, they varied from 173 to 194.24 µScm-1. By these, the soil electrical conductivity values were increased by 11.43 to 23.03%.

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

S/N	Treatment code	Soil electrical conductivity before remediation (µScm-1)	Soil electrical conductivity after remediation (µScm-1)	Effect of Ecorem treatment on soil electrical conductivity (%)
Crude oil series				
1.	Soil + CDO +Ecorem-675g	151.75±6.65	173±81	14.00
2.	Soil + CDO + Ecorem-810g	157.50±8.39	175.50±25.68	11.43
3.	Soil + CDO+ Ecorem -945g	158.25±12.18	177.50±14.89	12.16
4.	Soil + CDO + Ecorem -1080g	152±16.51	187±38.80	23.03
5.	Soil + CDO + Ecorem -1215g	160.50±15.93	194.25±25.90	21.02
Spent engine oil series				
6.	Soil + SEO + Ecorem -675g	152.50 ±20.73	188.25±32.28	23.44
7.	Soil + SEO + Ecorem -810g	160.50±16.34	182±11	13.40
8.	Soil + SEO +- Ecorem 945g	148±9	213±20	43.92
9.	Soil + SEO +- Ecorem 1080g	143.25±15.31	182.75±39.91	27.57
10.	Soil + SEO + Ecorem -1215g	156.25±1.44	243±56.87	55.52

SEO = spent engine oil, CDO = crude oil, for each mean value, n = 4

Effect relative to original and contaminated soil electrical conductivity values: The effect of Ecorem treatment relative to soil initial electrical conductivity value and that in contaminated soils are presented in Figs. 2 and 3. Results presented in Fig.2, showed that the utilization of Ecorem in the remediation of soils contaminated with spent engine oil increased the soil electrical conductivity in the range of 182 to 243.56 µScm-1. These values exceeded the mean value for uncontaminated soils by 14.29 to 52.94% and that contaminated soils, which received treatment were exceeded by 19.87 to 60.42%. Results, shown in Fig.3, showed that the utilization of Ecorem in the remediation of soils contaminated with crude oil increased the soil electrical conductivity in the range of 173 to 194 µScm-1. These values exceeded the mean value for uncontaminated soil by 8.63 to 21.82% and contaminated soil that received no Ecorem supplement by 27.21 to 42.65%.

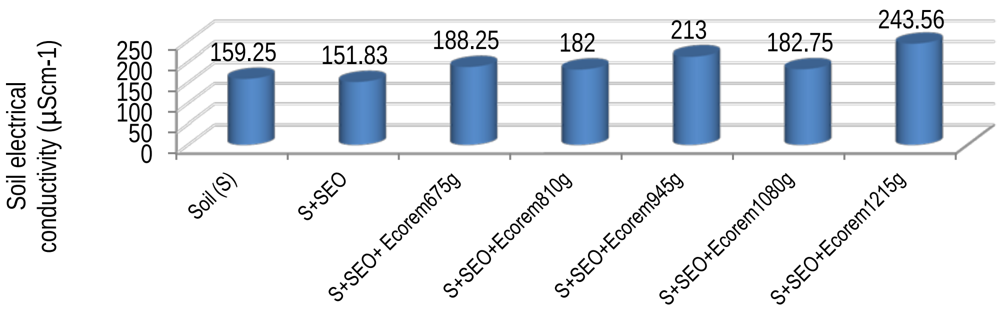

Fig.2: Electrical conductivities for uncontaminated soil, contaminated soil and soils contaminated with spent engine oil but treated with Ecorem supplement for 33 days

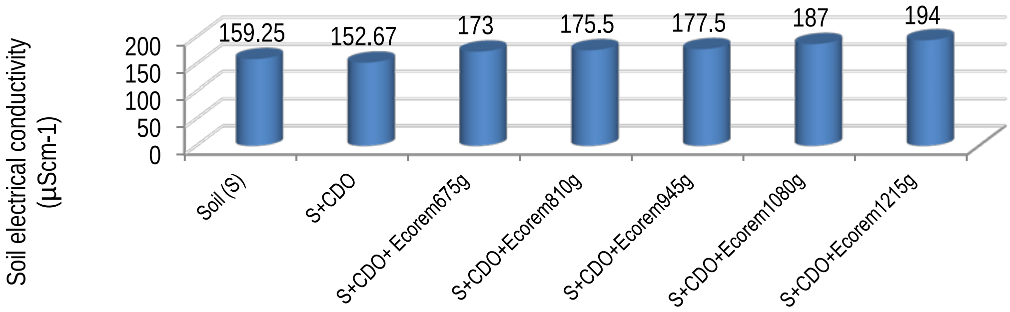

Fig.3: Electrical conductivities for uncontaminated soil, contaminated soil and soils contaminated with crude oil but treated with Ecorem supplement for 33 days

Electrical conductivity 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 electrical conductivity per 1% (w/w) of Ecorem to soil ratio was 2.540 μScm^{-1}. A positive correlation with a coefficient (r) of 0.683 ($p = 0.221$) was obtained within Ecorem - soil ratio range of 23 to 41% (w/w). For CDO series presented in Fig 5, soil electrical conductivity values were also positively impacted by Ecorem -soil weight ratio. Linear regression showed that the change in soil electrical conductivity per 1% (w/w) of Ecorem to soil composition was 1.197 μScm^{-1}. A positive correlation with a coefficient (r) of 0.967, significant at $p = 0.01$ was obtained within Ecorem - soil composition range of 23 to 41%.

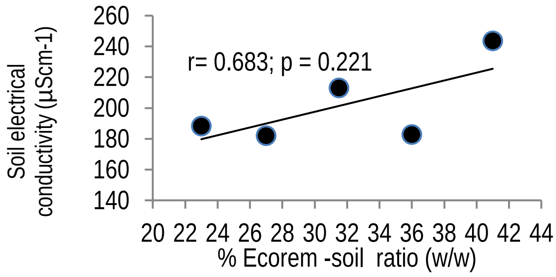

Fig.4: Relationship between soil electrical conductivity and the dose of Ecorem applied during remediation to soils contaminated with spent engine oil

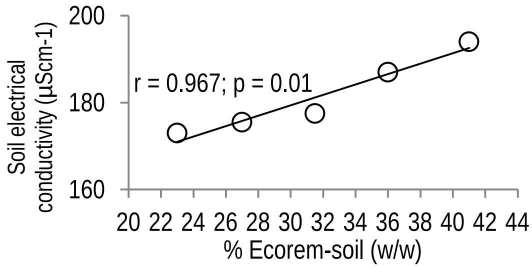

Fig.5: Relationship between soil electrical conductivity and the dose of Ecorem applied during remediation to crude oil contaminated soil

Predicting impact of Ecorem on soil electrical conductivity during bioremediation

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

$$P_{EC} = 2.540\, f_{Ecorem} + 121.3 \quad (1)$$
$$P_{EC} = 1.197\, f_{Ecorem} + 143.4 \quad (2)$$

where P_{EC} is the predicted electrical conductivity and f_{Ecorem} stands for percentage Ecorem-soil ratio (w/w). The soil electrical conductivity generated by the prediction models and the actual values obtained during the study are compared in Figs.6 and 7.

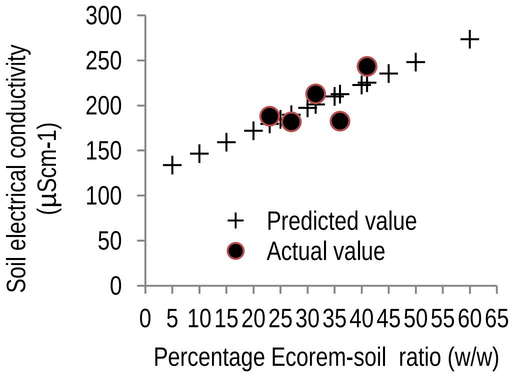

Fig. 6: Comparison between predicted and actual soil electrical conductivity on application of Ecorem for soils contaminated with spent engine oil

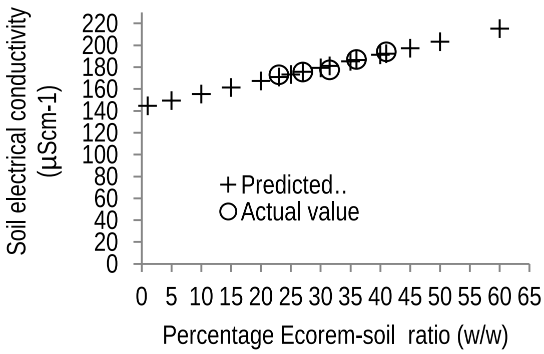

Fig. 7: Comparison between predicted and actual soil electrical conductivity on application of Ecorem for soils contaminated with crude oil

Results showed that for soils contaminated with spent engine oil, comparative evaluation for predicted and actual impact of Ecorem usage on electrical conductivity during bioremediation is presented in Fig.6. The respective predicted and actual EC values were179.72: 188.25 µScm^{-1} for Ecorem-soil ratio 23%, 201.31: 213 µScm^{-1} for ratio 31.5%, and 225.44 ; 243.56 µScm^{-1} for ratio 41%. These results showed that the predicted ECs were less than the actual ECs by 4.75%, 5.81% and 8.03% respectively. However, at ratios 27% and 36%, the respective predicted and actual EC values were 189.88; 182 µScm^{-1} and 212.74: 182.75 µScm^{-1}, showing that the predicted ECs exceeded the actual ECs by 4.33% and 16.41%.

In the case of soils contaminated with crude oil (Fig.7), at Ecorem-soil ratios 23%, 36% and 41%, the respective predicted and actual EC values were 170.93: 173 µScm^{-1}, 186.48: 187 µScm^{-1}and 192.27: 194 µScm^{-1}. These showed that the predicted values were less than the actual EC values by 1.21%, 0.28% and 0.90% respectively. On the contrary, at ratios 27% and 31.5%, the respective predicted and actual EC values were 175.72: 175.52 µScm$^{-1.}$ and 181.11: 177.5 µScm$^{-1,}$ showing the predicted EC values exceeded the actual EC values by 0.11% and 2.03% respectively.

The decreases of 4.88% and 4.31% in soil electrical conductivity as recorded in this study on introduction of SEO and CDO into the soil was attributed to suppression of the available ions in soil water, probably due to hydrophobic property of the oil. Soil electrical conductivity is an indication of total dissolved ions in soil solution and viewed as the quantity of available nutrients in the soil because only nutrients that are dissolved in the soil water are available for crops to absorb and take in [18]. Results therefore indicated that the spill of SEO or CDO has the potential to reduce soil fertility by hindering the release of nutrients into the soil solution.

As a guideline, soil electrical conductivity values below 200 µScm^{-1} indicate nutrient deficiency in soil [16]. Based on the results (159.25 ±9.25 µScm^{-1}) obtained in this study, the control (soil without oil contamination) was nutrient deficient. Electrical conductivity correlates strongly to soil particle size and texture. Sandy soils have a low conductivity, silts have a medium conductivity, and clays have a high conductivity [16]. The soil used in this study was sandy, explaining why the values obtained in this study for the original soil electrical conductivity status below 200 µScm^{-1}.

Increased soil electrical conductivity by utilization of Ecorem, regardless of product-soil ratio, implied the potential for improved soil nutrient status and consequently soil fertility, corroborated by the report of [12] by the product. This effect was attributed to contents of plant nutrients such as zinc, copper and chromium contained in the product as presented in previous reports [14]. This is also an issue that must be handled with care because if these elements are not at the appropriate concentrations, there may be the potential for heavy metal accumulation in the treated soil. For this purpose the feedstock and finished product must be screened for metal contents for compliance to standards as suggested by [13].

Electrical conductivity gives a close estimate of the amount of salt in a soil. There is a direct bearing between the soil electrical conductivity and soil salinity: the more the salts, the higher the electrical conductivity. A saline soil contains sufficient soluble salts that adversely affect crop growth and production. As a general guideline, a good soil electrical conductivity level lies in the range of 200 and 1200 μScm^{-1}. Values below 200 μScm^{-1} indicate nutrient deficiency in soil and values above 1, 200 μScm^{-1} are indicative of saline soil [16]. Results from this study revealed that by bioremediation of soils impacted by petroleum products using Ecorem, though led to increased soil electrical conductivity, did not render the soil saline as the highest soil electrical conductivity obtained after the remediation was 225.44 μScm^{-1}.

The feedstock used in the preparation of the Ecorem and type of formulation play vital roles on the ultimate influence of the technology on soil electrical conductivity. Fortification of the bioremediation product with inorganic salts will result in products characterized by high electrical conductivity. When this situation of increased salinity exists, after the hydrocarbons in the contaminated soils the treated soil will require further remedial measure to reduce salt content. The success story is that the product (Ecorem) used in this study, which was not treated with salts or any type of inorganic nutrient enhancement did not render the treated soils saline because the resultant electrical conductivity of soil was at the lower end of the accepted standards. This reduces the possibility of heavy metal accumulation in soils after remediation using Ecorem.

Positive correlations between Ecorem-soil ratio and electrical conductivity values were indications of increased soil electrical conductivity values with increasing load of Ecorem in soil during the remediation. It is therefore important to carry out evaluation studies to ascertain the optimum loading of the product in soil. The predictive modeling carried out in this study showed that even at the maximum Ecorem-soil ratio (41%) used in this study, the electrical conductivity did not exceed the maximum permissible electrical conductivity values of 1, 200 μScm^{-1} for agricultural soils. From simulation studies carried out in this work, at Ecorem – soil ratio of 60%, the electrical conductivity values was below 300 μScm^{-1} for crude oil series and spent engine oil series, respectively.

The simulation models generated in this study will provide important guide, in relation to soil electrical conductivity and salinity, for the planning of remediation works. For instance, results showed that for the remediation of soils impacted by spent engine oil, the predicted electrical conductivity value could fall below the actual value by 4.75 to 8.03% or exceed by 4. 33 to 16.41%. In the case of soils contaminated by crude oil, the predicted electrical conductivity value could fall below the actual value by 0.28 to 1.21% or exceed by 0.11 to 2.03%. 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 9% and a marginal positive error of 17%. For the remediation of crude oil contaminated soils, the errors are much more reduced: a marginal negative and positive error of 2% should be taken into consideration. The addition of these waste materials will not result in excessive end product material volume because at the close out of the remediation project, the organic wastes are expected to have undergone about 65% reduction in volume [14].

CONCLUSIONS

Based on the findings from this study, it was concluded that (i) soil contamination with either crude oil or spent engine oil decreased soil electrical conductivity, (ii) the application of Ecorem increased soil electrical conductivity but did not render the soil saline, (iii) a positive correlation was obtained between soil electrical conductivity readings and Ecorem-soil weight ratios and (iv) useful simulation models for soil pH predictive purposes for the planning of a bioremediation project using the product were generated.

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