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Impact of Bioremediation Formulation from Nigeria Local Resource Materials on Moisture Contents for Soils Contaminated With Petroleum Products

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Abstract— ***Local content policy in Nigeria promotes the development of innovative indigenous technology aimed at contributing to national science and technological development. Consequently, bioremediation agent (Ecorem) was formulated from Nigeria local raw materials as a contribution to enhanced environmental performance in the petroleum sector. As part of evaluating kinetic mechanism of this product, this study was on the evaluation of the influence of Ecorem on moisture content of soils contaminated by crude oil and spent engine oil, as a part study on its effect on soil properties. Influence of product-soil weight ratio on moisture content was also examined. Result showed that Ecorem increased soil moisture content by 11 to 22 folds over the initial 1 to 3.65% of untreated soils, transformed the original soil from non-arable soil to arable status and did not render the treated soil waterlogged at close-out. The effect also varied with Ecorem – soil weight ratio, giving positive correlations with coefficients of up to 0.955(p = 0.011); which is a function of petroleum product type.***

Keywords—***environment, Nigeria, petroleum bioremediation, raw material development, soil moisture***

I. INTRODUCTION

Petroleum resource, which is pivotal to Nigeria economic status, has also been a primary contributor to significant environmental challenges in terms of pollution of terrestrial and aquatic environments. Oil spill, which is any intentional or unintentional action or omission resulting in the releasing, spilling, leaking, pumping, pouring, emitting, emptying or dumping of petroleum into the waters or onto lands from which it might flow or drain into said waters, or into waters outside the jurisdiction of immediate point of impact, is the bane of environmental problems in the Niger Delta region of the country, a phenomenon corroborated by the reports recently complied by [1]. Oil spill events in many countries outside Nigeria, especially in more technologically advanced countries attract rapid and adequate response for clean up and remediation actions. On the contrary, in most developing countries including Nigeria, prolonged delays in the reclamation of oil impacted surfaces, irrespective of the cause of spills, is not unusual with resultant conflicts that threaten national security and endanger global peace. As revealed by [1], the mainstay economic activity in the Niger Delta region of Nigeria where the oil bearing communities are located is agriculture; hence, land contamination/degradation in this region is a threat to sustainable agricultural development and food security in the nation. Land use factor should, therefore, 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.

Clean-up usually refers to activities that facilitate the recovery of free phase oil such as using devices to recover oil from land and sorbent pads to collect oil from water's surface. On the other hand, remediation is the act or process of removing residual contamination from the soil, groundwater, or other media. Remediation is required when concentrations of contaminants exceed or are expected to exceed predetermined levels for the type of resource that is impacted. 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 methods of treating oil impacted soils due to their environmentally friendly characteristics. Local content policy in Nigeria promotes the development of innovative indigenous technology aimed at contributing to national scientific and technological development. As a significant contribution to this policy and in promotion of need-based research and development in bioremediation and sustainable environmental technologies, bioremediation agent (Ecorem) was formulated from Nigeria local raw materials as a contribution to enhanced environmental performance in the petroleum sector.

Subsequently, study on process kinetics of one of such bioremediation products, referred to as Ecorem commenced in order to provide scientific data on eco-toxicological significance of the product. Kinetic variables understudied were soil pH, electrical conductivity, metal concentrations and microbial community, temperature dynamics and moisture content. The purpose of the study was to investigate the influence of the bioremediation product (Ecorem) on soil moisture content. Hence, the objectives of this work were to examine the (i) effect of petroleum product spill on soil moisture content (ii) impact of remediation using Ecorem on soil moisture content relative to soil original status and the remediated matrix (iii) influence of product-soil ratio on soil moisture content and (iv) relationship between product-soil ratio and soil moisture content.

II. MATERIALS AND METHODS

Description of bioremediation formulation

Readily accessible natural organic waste materials of plant and animal origin, sourced in Nigeria, were formulated via composting technology. The basics of the composting procedure were described in the reports of [2,3,4]. The composted wastes were then modified with some naturally occurring, biodegradable materials, also locally sourced to give a technical product denoted as "Ecorem".

Soil contamination with petroleum products

Soil sample (about 60Kg bulk soil) was collected from a remote area within the campus (where there was no obvious source of petroleum pollution) 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 [5]. This was followed by soil transfer to designated experimental pots; being 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 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.

Table 1: System designs for 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 moisture content

Soil moisture content was assessed by gravimetric method via determination of the moist and dry weights. A grid template was established on the soil surface of each pot system at three different phases (pre-oil spill phase, pre-remediation phase and post remediation phase). Approximately 2g soil was collected from the different grid segments, mixed thoroughly to form a composite sample. A portion was collected from the composite from each pot, transferred into a vessel of weight (W_1) weighed on an analytical balance to give a weight (W_2) and oven dried at 105° C to a constant weight (W_3). The mass of water lost was then related to the initial weight and multiplied by a factor of 100 to obtain the percentage soil moisture content (SMC) as described in equation (1):

$$\% \text{ SMC} = W_2\text{-}W_3/W_3\text{-}W_1 \times 10^2 \ldots (1)$$

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 moisture content.

III. RESULTS AND DISCUSSION

Results

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 of oil contamination on soil moisture content

The overall mean moisture contents for uncontaminated soil and soils contaminated with petroleum products (CDO and SEO) are presented in Fig.1. Introduction of the petroleum products into the soils increased their moisture contents. The soil mean moisture contents before contamination with either CDO or SEO was 1%. The introduction of CDO raised the value to 1.08 ± 0.29%, corresponding to 8% increase. Contamination of the soil with SEO caused an increase of 9%, raising the original moisture content from 1% to 1.09±0.29%.

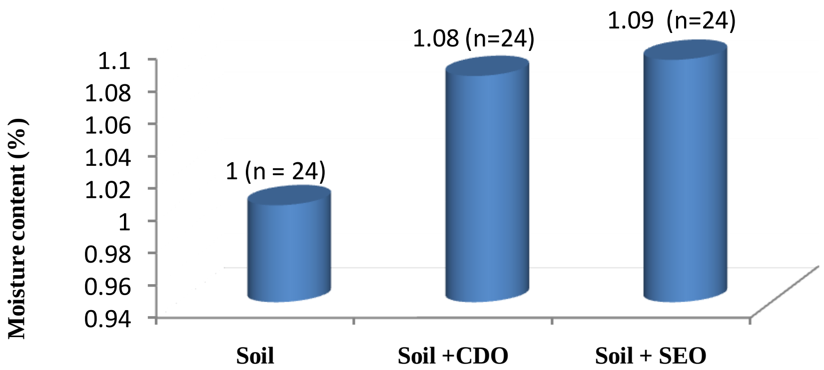

Fig.1: Moisture contents in uncontaminated soils and soils contaminated with crude oil (CDO) and spent engine oil (SEO)

Absolute effect of Ecorem on soil moisture content and effect relative to original and contaminated soil electrical conductivity values

The values for soil moisture contents before remediation and after treatment using Ecorem 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 moisture status. The initial values for oil contaminated soils ranged from 1% to 1.25% but after remediation the varied from 13.61 to 20.41% for crude oil series and 14 to 22% for SEO series. By these, the soil moisture contents were generally increased by factors of 11 to 22 due to remediation using Ecorem. At the end of remediation, the mean values for moisture contents in all the systems were presented in Figs.2 and 3. The mean moisture content of uncontaminated soil was 1.25±0.50% and that for crude oil and spent engine oil contaminated soils were 3.53±1.23% and 3.69±0.99% respectively. The effect of Ecorem treatment relative to soil initial moisture content and that in contaminated soils are also 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 moisture content in the range of 17.35 to 22.34%. These values exceeded the mean value for uncontaminated (S) and contaminated soils (S+SEO) by 13.88 to 17.87 and 4.71 to 6.05 folds respectively. On the other hand, results presented in Fig.3, showed that the utilization of Ecorem in the remediation of soils contaminated with crude oil increased the soil moisture content in the range of 13.61 to 20.41%. These values exceeded the mean value for uncontaminated (S) and contaminated soils (S+CDO) by 10.89 to 16.33 and 3.86 to 5.78 folds respectively.

Table 2: Soil electrical conductivity before remediation, after remediation and treatment impact

S/N	Treatment code	% Soil moisture content before remediation	% Soil moisture content after remediation	Incremental factor of remediation process on soil moisture content
Crude oil series				
1.	Soil + CDO +Ecorem-675g	1.25±0.5	13.61±3.68	11
2.	Soil + CDO +Ecorem-810g	1.0±0	16.79±2.55	17
3.	Soil + CDO+Ecorem-945g	1.0±0	18.16±4.66	18
4.	Soil + CDO +Ecorem-1080g	1.0±0	18.73±3.15	19
5.	Soil + CDO +Ecorem-1215g	1.25±0.5	20.41±4.65	20
Spent engine oil series				
6.	Soil + SEO +Ecorem-675g	1.25±0	17.35±3.0	14
7.	Soil + SEO +Ecorem-810g	1±0	17.59±1.73	18
8.	Soil + SEO +Ecorem-945g	1±0	17.93±0.82	18
9.	Soil + SEO +Ecorem-1080g	1±0	19.55±1.72	20
10.	Soil + SEO +Ecorem-1215g	1±0	22.34±6.32	22

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

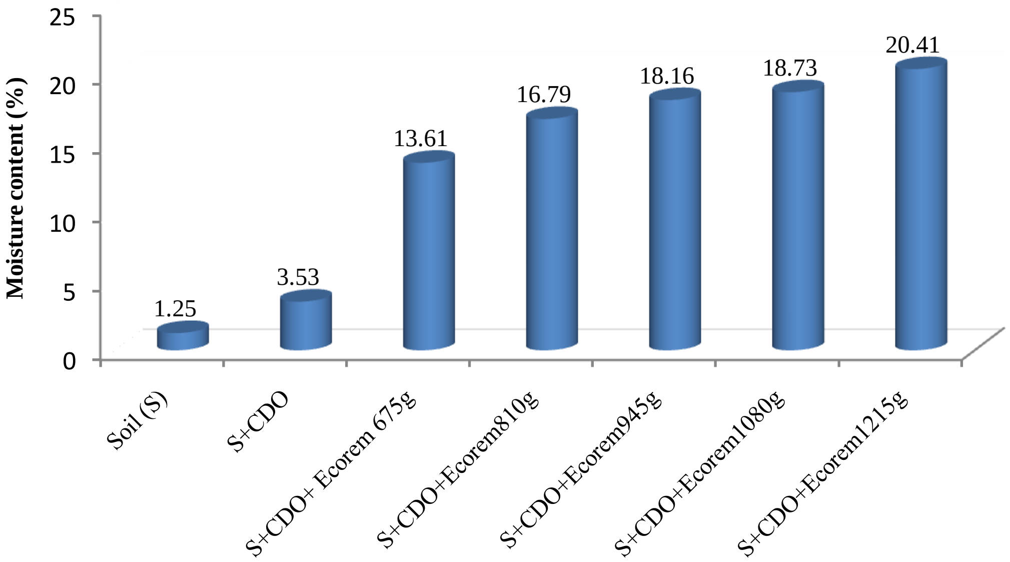

Fig.2: Moisture contents at remediation close-out for soils contaminated with crude oil

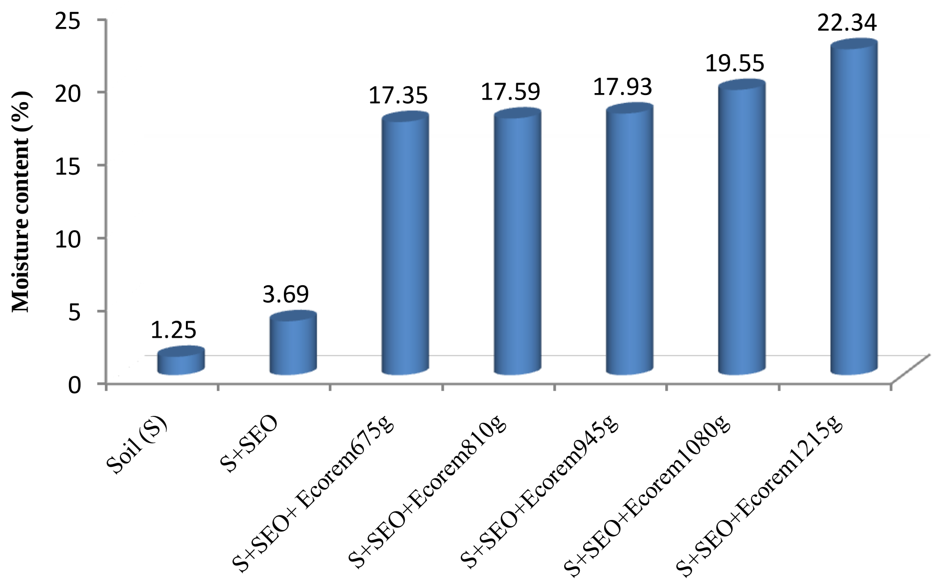

Fig.3: Moisture contents at remediation close-out for soils contaminated with spent engine oil

Correlation between soil moisture content and Ecorem-soil weight ratios

Soil moisture content values were positively impacted by Ecorem-soil weight ratios as shown in Figs.4. For SEO series (Fig.4), data from linear regression showed that the change in soil moisture content per 1% (w/w) of Ecorem to soil ratio was 0.269%. A positive correlation with a coefficient (r) of 0.922; p = 0.026, was obtained within a Ecorem- soil weight ratio range of 23 to 41% (w/w). 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 0.342%; positive correlation with a coefficient (r) of 0.955; p = 0.011, was obtained within percentage weight ratios of 23 to 41%.

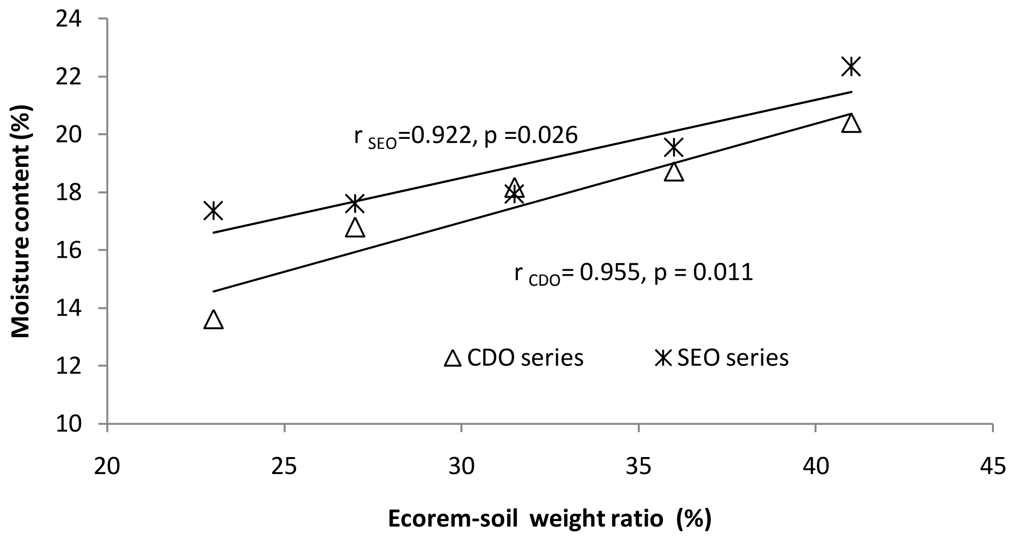

Fig.4: Relationship between soil moisture contents and Ecorem-soil weight ratios

Discussion

The increase of about 1% in soil moisture content that was recorded in this study on introduction of SEO and CDO into the soil was attributed to oil's aggregation of soil particles that could have lowered soil porosity, increased soil hydrophobic characteristics and increased resistance to water penetration. This also explains the suppression of the available ions in soil water by oil contamination as recorded in the reports of [6]. Oil aggregation of soil particle has the potential to impact negatively on the growth and productivity of crops grown in such contaminated soils system. Optimum soil water contents in arable Nigerian soils are in the range of 13 to 26 % [7, 8, 9, 10]. Consequently, based on moisture contents, the control (soil without oil contamination, characterized by moisture content of 3.65%) was not suitable for crop production in contrast the results on soil moisture content (17 to 22%) in remediated soil obtained in this study. By implication, the utilization of Ecorem increased the hydrophilic properties of the soil and increased the soil moisture level to that suitable for crop production.

The increase in soil moisture content by the remediation method used in this study was attributed to hydration mechanisms, in which Ecorem absorbed and retained water. It was also attributed to increased evaporation process in the soils that did not receive Ecorem; contrary to the reduced evaporation mechanism in soil systems that were treated with Ecorem. By implication the remediation agent (Ecorem) hindered the release of soil water to the atmosphere through evaporation by shielding the soil from the intense tropical solar energy. As a result, the use of Ecorem plays a positive role against soil draught and crop protection against global warming. Increased soil moisture contents by utilization of Ecorem, regardless of product-soil ratio, implied the potential for improved soil hydraulic characteristics and consequently soil fertility because this will enhance the solubilization of plant nutrient elements into soil water and render them more bioavailable for plant uptake. Ecorem itself is enriched with plant nutrient elements as reported by [2, 3], hence, these nutrients such as zinc (Zn), copper (Cu) and chromium (Cr) will be further enrich soil water matrix. To prevent accumulation of these metals (Zn, Cu, Cr) in remediated soil, the feedstock used in the formulation of the remediation agent and the finished product must be screened for metal contents for compliance to standards as suggested by [2]. Based on the report of [6] the resultant electrical conductivity of soil was at the lower end of the accepted standards, thus reducing the possibility of heavy metal accumulation in soils after remediation using Ecorem.

Variation in soil moisture characteristics for the applied Ecorem-soil weight ratios suggests differential transmissivity of soil water with different Ecorem loadings in these soils. Positive correlations between Ecorem-soil ratio and soil moisture contents were indications of increased soil hydraulic property with increasing load of Ecorem in soil during the remediation. Although results from this study revealed that by bioremediation of soils impacted by petroleum products using Ecorem, at the close-out of the exercise, the soils were not water logged.

IV. CONCLUSIONS

Based on the findings from this study, it was concluded that (i) soil contamination with either crude oil or spent engine oil increased soil moisture content, (ii) the application of Ecorem increased soil moisture content, transforming the non-arable soil (in terms of water content) to an arable soil but did not render the soil water logged at close-out and (iii) positive correlations were obtained between soil moisture contents and Ecorem-soil weight ratios .

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