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Soil Temperature Dynamics during Bioremediation of Petroleum Products Using Remediation Agent Made from Nigeria Local Resource Materials

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

[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

Abstract

Effect on soil temperature (ST) regime was assessed for a bioremediation product (Ecorem) made from local resource materials from Nigeria as part process kinetic study to establish its eco-toxicological significance. Influence of Ecorem-soil weight ratios (ESWR) was examined and predictive equations developed. Results showed daily temperatures fluctuations. Poled data revealed up to 4.4% ST (37.41 ±1.85^{o}C) reduction by oil contamination. Ecorem increased the value by 1.12 to 3.93%. Temperature elevation varied with ESWR, giving positive correlations with coefficients of up to 0.950 (p = 0.013); which is a function of petroleum product type. However, study revealed that bioremediation using Ecorem runs at temperature variations favourable to improved crop production and from predictive equations, remediation project execution plans using Ecorem; for soils contaminated by petroleum products such as spent engine oil and crude oil, negative and positive errors of - 1.23% and + 1.54% from mean ST are recommended.

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

1. Introduction

Nigeria is reputed as the most populous country in Africa, whose economy revolves around petroleum resources. The oil wells are located in the southern region of the country, precisely the Niger Delta. Over a period of time, the environmental issues related to petroleum exploration and productions were not effectively addressed. However, in the recent past, neglect of deteriorated environment in the region has drawn both national and International attention. One of the many options in managing the conflicts resulting from the relegated environmental issue is to adequately restore the environment to its original functionality. The most common land use in the Niger Delta region is farming [1]; adequate restoration would imply the transformation of the oil impacted environments for sustainable agriculture.

As a contribution to the promotion of local content policy in the study of petroleum and environment in Nigeria, research has been ongoing in the development of resource materials in the formulation of case specific bioremediation technologyt, suitable for the Nigeria conditions [2, 3, 4]. Currently, study on process kinetics of one of such bioremediation products, referred to as Ecorem is ongoing. This is necessary because it will provide an in-depth understanding of eco-toxicological significance of the product. Kinetic factors under study include soil pH, electrical conductivity, metal concentrations and microbial community.

This particular work dwells on the changes in temperature regime during utilization of Ecorem in the treatment of soils impacted by petroleum products (crude oil and spent engine oil). It is well known that the success of soil remediation process (physical, chemical, thermal and biological) to some extent depend on environmental factors such as pH, oxygen and temperature; these processes in turn affect environmental factors that influence the utility of treated soil. An example of such factors is soil temperature. Soil temperature, is a measure of the degree of hotness or coldness of a particular soil, varies in response to treatment processes that take place primarily through the soil surface. In most parts of the tropical wet and dry climate, thermal meteorological parameters such as soil temperature form part of critical considerations in crop production and an important component of the plant environment in a tropical wet-and-dry climate.

Although temperature is very important for a successful remediation project, excessive temperature regime in soil while bioremediation is ongoing or at the end of the remediation project is not desirable as elevation of soil temperature may adversely impact on crop productivity and yield [5 6]. Consequently, the emphases of this particular report are (i) the effect of petroleum product spill on soil temperature (ii) the impact of remediation using Ecorem on soil temperature values relative to soil original status and the remediated matrices (iii) influence of Ecorem-soil weight ratios on soil temperature and (iv) simulation of Ecoremt-soil weight ratios on soil temperature for predictive purposes.

2. Materials and methods

2.1 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".

2.2 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 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] 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.

2.3 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 compost-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.

2.4 Assessment of soil temperature

The method of [6] was adopted with slight modification.

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

Soil temperature was measured using a soil temperature thermometer and values were read in-situ at the experimental site. Soil mercury-in-glass thermometers were used to measure the bare soil temperature for all the systems described in Table 1. In each system, 4 holes, spaced at 45 cm, were made in the soil to a depth range of 0-15 cm. Soil thermometers were then inserted and good contact between the soil and the thermometers was maintained. This was carried once a day between 12 noon and 1 pm for a given period of time between 19 and 21days for the different treatments

2.5 Prediction of soil temperature 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 temperatures obtained during the study.

2.6 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.

3. Results and discussion

3.1 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

3.3 Effect of oil pollution on soil temperature

The overall mean temperature values for uncontaminated soils and soils contaminated with petroleum products (CDO and SEO) are presented in Fig.1. Introduction of the petroleum products into the soils reduced their temperature values. The soil mean temperature value before contamination either with CDO or SEO was 37.41±1.85 ^{o}C. The introduction of SEO decreased the value to 36.02±1.63 ^{o}C, corresponding to a 3.85% decrease. Contamination of the soil with CDO gave a decrease of 4.44%, reducing the original temperature status from 37.41±1.85 to 35.82 ±1.45^{o}C. The detailed descriptive statistics (Table 2), showed that the maximum temperature values attained during the experiments were 40.11 ^{o}C for uncontaminated soil, 37.75^{o}C for soils contaminated with crude oil and 38.34 ^{o}C for soils contaminated with spent engine oil.

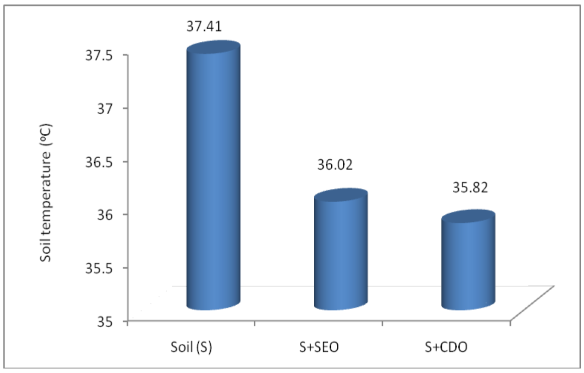

Figure 1: Temperature values for uncontaminated soil and those contaminated with petroleum products

Table 2: Detailed descriptive statistics for uncontaminated soils, soil contaminated with crude oil (CDO) and soil contaminated with spent engine oil (SEO)

System code	Statistics							
	N	Range	Minimum	Maximum	Mean	Std. Error	Std. Deviation	Variance
Soil alone (S)	20	7.80	32.31	40.11	37.4115	.41429	1.85276	3.433
S + CDO	20	6.29	31.46	37.75	35.8230	.32535	1.45500	2.117
S + SEO	20	6.40	31.94	38.34	36.0200	.36361	1.62609	2.644

3.2 Daily soil temperature variations during bioremediation

Daily temperature regimes for uncontaminated soil and those contaminated with petroleum products are presented in Figs. 2 – 4. Each point on the graph was a mean value of 4 replicates. The temperature readings did not remain constant but fluctuated in a near sinusoidal pattern as the days progressed.

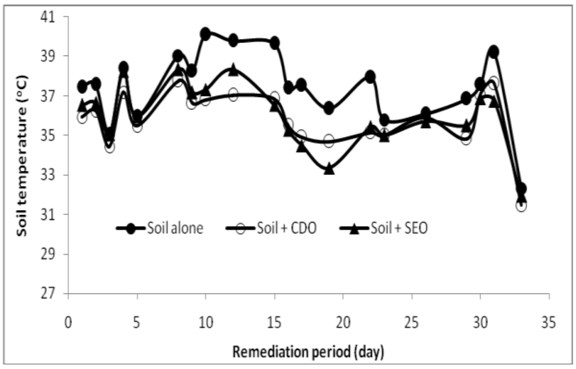

Figure 2: Daily temperature regimes for uncontaminated soil and those contaminated with petroleum products

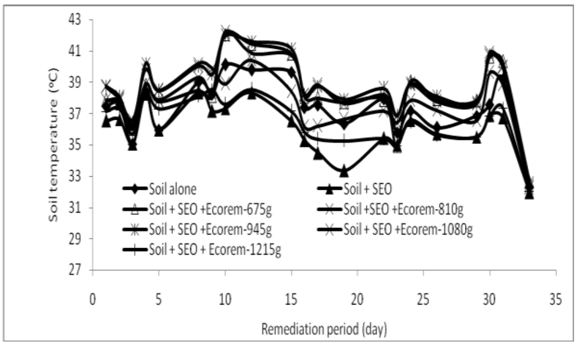

Figure 3: Daily temperature regimes for uncontaminated soil and those contaminated with spent engine oil (SEO)

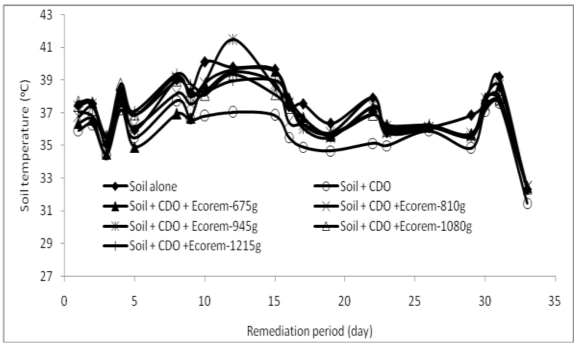

Figure 4: Daily temperature regimes for uncontaminated soil and those contaminated with crude oil (CDO)

The detailed descriptive statistics for temperature readings obtained for soils contaminated with the petroleum products during remediation, using different quantities of Ecorem, are shown in Table 3. For SEO series, results showed that the maximum temperature values attained during the exercise for the loadings varied from 38.54 to 42.20 °C with only one system recording a maximum temperature below 40 °C but for CDO series, the maximum temperature values attained during the exercise varied from 39.35 to 41.50°C with only one system recording a maximum temperature of up to 40 °C.

Table 3: Detailed temperature descriptive statistics for soils contaminated with spent engine oil

System code	N	Minimum	Maximum	Mean	Std. Deviation
SEO series					
S +SEO +Ecorem675g	21	32.66	42.04	38.2781	2.13674
S+SEO+Ecorem810g	21	32.43	42.20	38.4467	2.02670
S+ SEO+Ecorem945g	21	32.60	41.96	38.7714	2.05416
S+SEO+Ecorem1080g	21	32.24	40.40	37.8143	1.88839
S+SEO+Ecorem1215g	21	34.90	38.54	36.8133	1.14393
CDO series					
S+CDO+Ecorem675g	19	34.50	39.65	37.0579	1.45058
S+CDO+Ecorem810g	19	35.24	39.48	36.9984	1.16993
S+CDO+Ecorem945	19	35.49	41.50	37.4279	1.49230
S+CDO+Ecorem1080g	19	32.35	39.35	37.1511	1.66773
S+CDO+Ecorem1215g	19	35.49	39.39	37.2768	1.19429

3.4 Effect of bioremediation using Ecorem on mean temperature value for soils impacted by petroleum products

The mean temperature readings, throughout the remediation exercise, for uncontaminated soil, those contaminated with petroleum products and the treated soils are shown in Figs.5 and 6. For SEO series (Fig.5), the mean values for treated soils ranged from 38.28 to 38.88°C for the different applied Ecorem doses. Relative to the original soil temperature (37.41°C) treatment increased the value by 2.33 to 3.93%. This temperature elevation gave a positive linear relationship with applied Ecorem dose with coefficient of correlation (r) of 0.950, significant at $p = 0.013$. For CDO series (Fig.6), the mean values for treated soils ranged from 37.83 to 38.03°C for the different applied Ecorem doses. Relative to the original soil temperature (37.41°C) treatment increased the value by 1.12 to 1.66%.

Temperature elevation increased with applied Ecorem with coefficient of correlation (r) of 0.880, significant at $p = 0.049$. Table 5 contains added information on % Increase in temperature relative to that of untreated oil contaminated soil (35.82 for CDO contamination and 36.02°C for

SEO contamination). Comparing the temperature readings of treated soils and the values obtained in untreated SEO contaminated soils (36.02°C), treatment raised the value by 6.27 to 7.94% and 5.71 to 6.7% in untreated CDO contaminated soils.

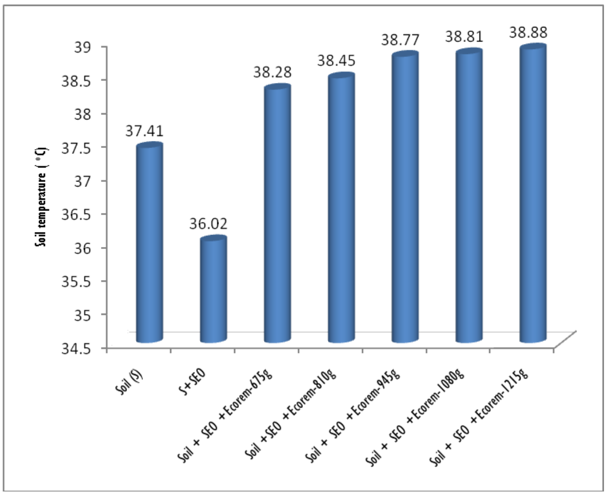

Figure.5: Mean temperature readings for uncontaminated soil and those contaminated with spent engine oil (SEO) throughout the remediation exercise; n = 21 for each mean value

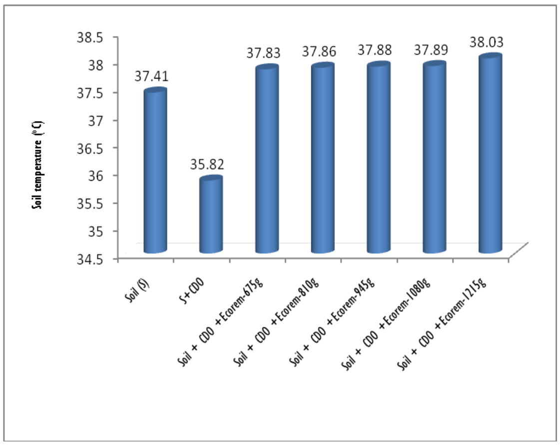

Figure 6: Mean temperature readings for uncontaminated soil and those contaminated with crude oil throughout the remediation exercise; n= 21 for each mean value

Table 5: Effect of remediation of soils contaminated with petroleum products using organic wastes recycled via composting technology

S/N	System code	% Increase in temperature relative to original soil status*	% Increase in temperature relative to that of untreated oil contaminated soil**
Remediation of SEO contaminated soils			
1.	S+ SEO+Comp675g	2.33	6.27
2.	S+ SEO+Comp810g	2.91	6.75
3.	S+ SEO+Comp945g	3.64	7.63
4.	S+ SEO+Comp1080g	3.74	7.75
5.	S+ SEO+Comp1215g	3.93	7.94
Remediation of CDO contaminated soils			
6.	S+ CDO+Comp675g	1.12	5.61
7.	S+ CDO+Comp810g	1.20	5.70
8.	S+ CDO+Comp945g	1.26	5.75
9.	S+ CDO+Comp1080g	1.28	5.78
10.	S+ CDO+Comp1215g	1.66	6.17

S= soil, CDO = crude oil, SEO = spent engine oil, * original soil temperature = 37.41°C, ** temperature of oil contaminated soil = 36.02 °C for S+SEO and 35.82°C for S+CDO.

3.5 Prediction of soil temperature during bioremediation using Ecorem

The overall mean soil temperature values were positively impacted by Ecorem-soil weight ratios in both cases. Data deduced from linear regression showed that the change in soil temperature per 1% (w/w) of Ecorem- soil weight ratio was 0.034°C for SEO series and 0.069 °C for CDO series. For the prediction of soil temperature values during bioremediation using Ecorem product, prediction models (i) and (ii) were used for soils contaminated by spent engine oil and crude oil respectively:

$$Tp = 0.034\, f_{Ecorem} + 37.55 \quad \ldots \text{(i)}$$
$$Tp = 0.069\, f_{Ecorem} + 35.25 \quad \ldots \text{(ii)}$$

f_{Ecorem} stands for percentage Ecorem-soil ratio (w/w) and Tp for predicted temperature. Soil temperature values generated by the prediction models and the actual values obtained during the study are compared in Figs.7 and 8. Results showed that for the remediated spent engine oil impacted soil systems (Fig.7), the predicted soil temperatures were slightly higher than the actual values by 0.83 to 1.54%.

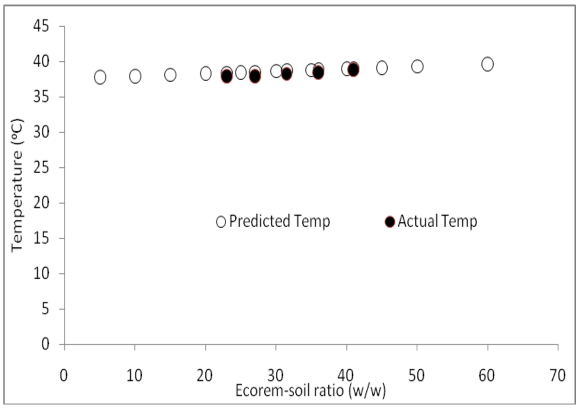

Figure 7: Comparison between predicted and actual soil temperature on application of bioremediation using Ecorem for soils contaminated with spent engine oil

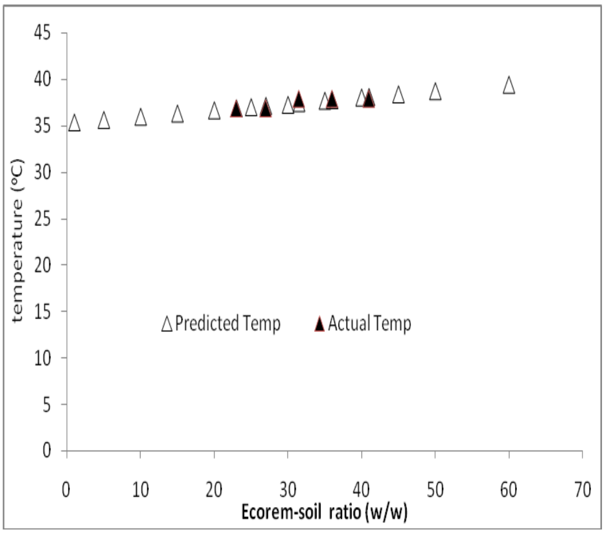

Figure 8: Comparison between predicted and actual soil temperature on application of bioremediation using Ecorem for soils contaminated with crude oil

Data from this study demonstrated that for the remediated crude oil impacted (Fig.8), at CS 23, 27 and 41, the respective predicted and actual pH values were 36.84: 36.83, 37.11:36.86 and 38.08:37:90. These results showed that the predicted pH values were higher than actual pH values by 0.27%, 0.68% and 0.47% respectively. However, at CS 31.5 and 36, the respective predicted and actual pH values were 37.42:37.88, 37.73:37.89. By these data, the predicted temperature values were less than the actual values by 1.23% and 0.42% respectively.

3.6 Discussion

The reduction of soil temperature by the introduction of the petroleum contaminant was an indication that soil contamination alters soil temperature, which in turn has the potential to impact on temperature related biochemical processes taking place in the soil. For instance, temperature is one of the most important soil factors that regulate the activity and determines the composition of the microbial community. If the temperature is changed, a selection pressure will be applied, altering the microbial community. Microbial species more adapted to the new conditions will grow faster, while those not well adapted will be outcompeted. Hence the spill of petroleum products can adversely affect soil microbial community, resulting in loss of biodiversity. This effect will reduce the activities of indigenous microorganisms, which could be a contributory factor to reduced efficiency of remediation by natural attenuation, making the process very slow [7, 8, 9, 10].

Soil temperature elevation via Ecorem utilization was in concordance with the report of [11] and was attributed to insulating characteristics of the feedstock (plant waste materials) which are not good heat conductors. Soil temperature elevation caused by Ecorem application suggests that this remediation method favors conditions suitable to increased soil microbial community, which in turn enhances biochemical process for hydrocarbon degradation.

Results from this study showed that although the pooled mean for soil temperature values indicated that the utilization of composted organic wastes led to increased soil temperature, the daily temperature profile demonstrated that the temperature at the end of the remediation was very much reduced relative to values suitable for tropical agriculture; 31.94 to 32.66^{o}C for SEO series and 31.46 to 32.46^{o}C for CDO series respectively. This is of importance because aside from microbial activities, temperature of the soil also significantly affects other agricultural processes and activities including planting root development seed germination, seedling emergence and growth. Soil temperature is a basic property required to evaluate most biological and physical processes in the soil-animal ecosystem [12].

The temperature range (31.46 to 32.66^{o}C) recorded in this study throughout the remediation exercise fell within the values reported for soil temperature values (28.2 to 34.20^{o}C) in agricultural land in different parts of Nigeria [12, 13, 14] and other tropical regions that have the optimal soil temperature range for plant growth that lie between 25 to 34^{o}C. Generally, crop yield rises with increase in soil temperature to a point and decreases with further increase in soil temperature [15]. It then implies that from the temperature profile recorded in this study, bioremediation using Ecorem runs at temperature variations that favor improved crop production. The report on the effect of this technology on growth of some tropical plants is being considered for publication elsewhere.

The elevation of soil temperature obtained in this study by the incorporation of Ecorem into the soil matrix, found to be influenced by the quantity of material added during treatment irrespective of the pollution type, is an indication that Ecoremt-soil ratio is a factor that should be considered in the execution of this bioremediation technology. The developed linear regression model proved to be a useful tool in the description of soil temperature as a function of Ecorem-soil weight ratio. From simulation studies carried out in this work, at the maximum Ecorem – soil ratio of 60%, the predicted soil temperature for crude oil series and spent engine oil.

The simulation models generated in this study will provide important guide, in relation to possible soil temperature values for the planning of remediation works using the Ecorem product. For instance, results showed that for the remediation of soils impacted by spent engine oil the predicted temperature values could exceed the actual value by 0.83 to 1.54%. In the case of soils contaminated by crude oil, the predicted soil temperature value could fall below the actual value by 0.42 to 1.23% or exceed by 0.27 to 0.68%. 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 positive error of 1.54% should be considered. For the remediation of crude oil contaminated soils, a marginal negative error of 1.23% be considered and positive error of up to 0.68% should be taken into consideration.

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