



Impact of Tillage Remediation on Soil Microarthropods and Nutrients in Hydrocarbon Contaminated Soil Ecosystem at Ikarama Community, Bayelsa State, Nigeria

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ABSTRACT: Impact of tillage remediation on soil nutrients and its relationship with soil fauna abundance in hydrocarbon contaminated soil ecosystem was assessed at Ikarama community, Bayelsa State, Nigeria, where Shell Petroleum Company, Nigeria carried out remediation. The assessment which lasted for six months was undertaken at three sites (1yr-3yr- Post remediated sites, control) each measured at 30m x 30m divided into four sub-plots in a split plot Design. Composite soil sampling was done each month at 5cm depth from each study site and taken to the laboratory for nutrient analysis including, total organic carbon, total organic matter, nitrogen, phosphorus, potassium and total hydrocarbon concentration. Results showed that total hydrocarbon concentration was 1.4038mg/kg (control), 237.3mg/kg (1yr-remediated) and 120.119mg/kg (3yr post remediated sites). Percentage total nitrogen was 6.826% (control), 5.386% (1yr-post remediated) and 5.985%mg/kg (3yr-post remediated). Total phosphorus and potassium was 15.408mg/kg and 7.516mg/kg (control), 14.078mg/kg and 8.626mg/kg (1yr-post remediated sites) and 16.403mg/kg and 7.912mg/kg (3yr post remediated sites). The control sites recorded a concentration of 26.36% total organic carbon, and 45.45% total organic matter. At 1yr post remediated sites, it was 49.18% total organic carbon, 84.79% total organic matter. In 3yrs post remediated sites, total percentage organic carbon was 38.86% and total organic matter was 67.01%. Abundance of soil microarthropods was recorded as 375 (control), 88 (1yr post remediated) and 162 (3yr- post remediated) sites. Tillage remediation indicated that the ecosystem is returning at a very slow rate, as there was a slight decrease in organic nutrients from the control to the remediated sites.

Keywords: Organic matter, organic nutrients, remediated sites, soil nutrients, soil microarthropods, total hydrocarbon concentration.

INTRODUCTION

Hydrocarbon contaminated soil ecosystem is an ecosystem which has been polluted by crude oil spills, leakages from pipelines. Oil spills involve the release of dangerous hydrocarbons such as benzene and Polycyclic Aromatic Hydrocarbons (PAHs) into the environment, including the soil (Legborsi,

2007). In this soil ecosystem, the availability of nutrients and its distribution which is usually controlled by fossorial arthropods including soil microarthropods is altered. Soil microarthropods are fossorial arthropods generally less than 2mm in sizes, which except with some level of magnification (Badejo, 1998, Chinelo *et al.*, 2014) do not permit an in depth study of their morphological features with the naked eye (Kapp *et al.*, 2013). They live along with other fossorial arthropods whose detail morphological features

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can be studied without magnification at soil surfaces, interphases, and top soil, feeding on decaying vegetation, bacteria, fungi, protists and nematodes (Holowko, 2010), where they are often subjected to chemical deterioration from hydrocarbon contamination caused by crude oil spills, and leakages of pipelines. A total of 3,291 spills had occurred within 2007 and 2012 with an average of 549 per year in the Niger Delta (Ikarama inclusive) (NOSDRA, 2015). Some effects of such contamination included death of soil fauna due to asphyxiation (Osaji and Onojake, 2006), decrease in the abundance and changes in vertical migration of soil microarthropods (Gbarakoro *et al.*, 2011). In an attempt to reverse the alteration, some remediation measures are adopted, and notable among them is the application of tillage remediating agent.

Tillage is a conventional process usually employed to accelerate recovery of contaminated ecosystem (Oyedeleji, 2016). Remediation is a much safer and less expensive process that is increasingly gaining value in treating contaminated soil returning them to their pre-disturbance level (Pereira and Alves, 2012). The most common type of remediating process is the *in-situ* form and it is used worldwide (Wuana and Okiamen, 2011). Tillage is a cleanup approach usually conducted at the site (*in-situ*) of pollution such that the pollutant can be removed without disturbing the environment.

Remediation adopted a positive result in studies carried out by Imasuen *et al.*, (2014) in Koko and Ajoke communities, Niger Delta, Nigeria, which drastically reduced total Nitrogen and Phosphorous. This was accredited to the remediating agent and indicates that the remediation process used had no restoration effect on soil parameters as the remediating agent consumes it in remediation process. According to Tanee and Albert (2011), nutrients of both the remediated site and un-remediated site as regarding nitrates and phosphate did not show appreciable differences, hence the process of remediation was effective. Reduction of nutrients in the soil may be attributed to microbial degradation which enabled the utilization of available nutrients for their metabolic activities (Das and Chandram,

2010). Also the THC value of the remediated site as compared to the polluted and control sites reduced due to the remediation process whereby microorganisms utilized the hydrocarbon as energy source for their metabolic activities (Tanee and Albert, 2011, Adams *et al.*, 2015). A similar occurrence was also noted by Ayotamuno *et al.*, (2006) where results showed a noticeable reduction in percentage THC and organic content of the soil in the remediated sites. The form of remediation (applied fertilizer and tillage) increased hydrocarbon degradation.

Tillage (*in-situ*) was the remediation process used by Shell Nig. Ltd. in the remediation of contaminated sites at Ikarama community. Remediation from available literature has been known to: (i) reduce soil nutrients when the process is on-going, (ii) be effective as no appreciable difference in nutrients was observed between remediated and unremediated sites, (iii) reduce THC values in the remediated sites, by increasing its degradation where a combination of fertilizers and tillage was the remediating agent. Furthermore, since the fossorial arthropods have the capacity to control nutrient availability for and perhaps uptake by plants (Schowalter, 2011), the present study was undertaken with the following objectives;

- (i) To assess the impact of tillage remediating agent on soil nutrients in hydrocarbon contamination soil ecosystem.
- (ii) To evaluate the relationship between available soil nutrients and abundance of soil microarthropods in a tillage remediating hydrocarbon-contaminated soil.

MATERIALS AND METHODS

Study Area

The study was conducted at Ikarama community, Yenagoa Local Government Area, Bayelsa State, Nigeria. Three sites; the remediated sites which were one year post remediated site (Site A) called "12" Adibawa-Okordia Manifold right of way ($5^{\circ}09' 19.851''$ N and $6^{\circ}27' 06.882''$) and a three year post remediated site (Site B) named "14" Okordia-Rumuekpe Pipeline ($5^{\circ}08' 05.7228''$ N

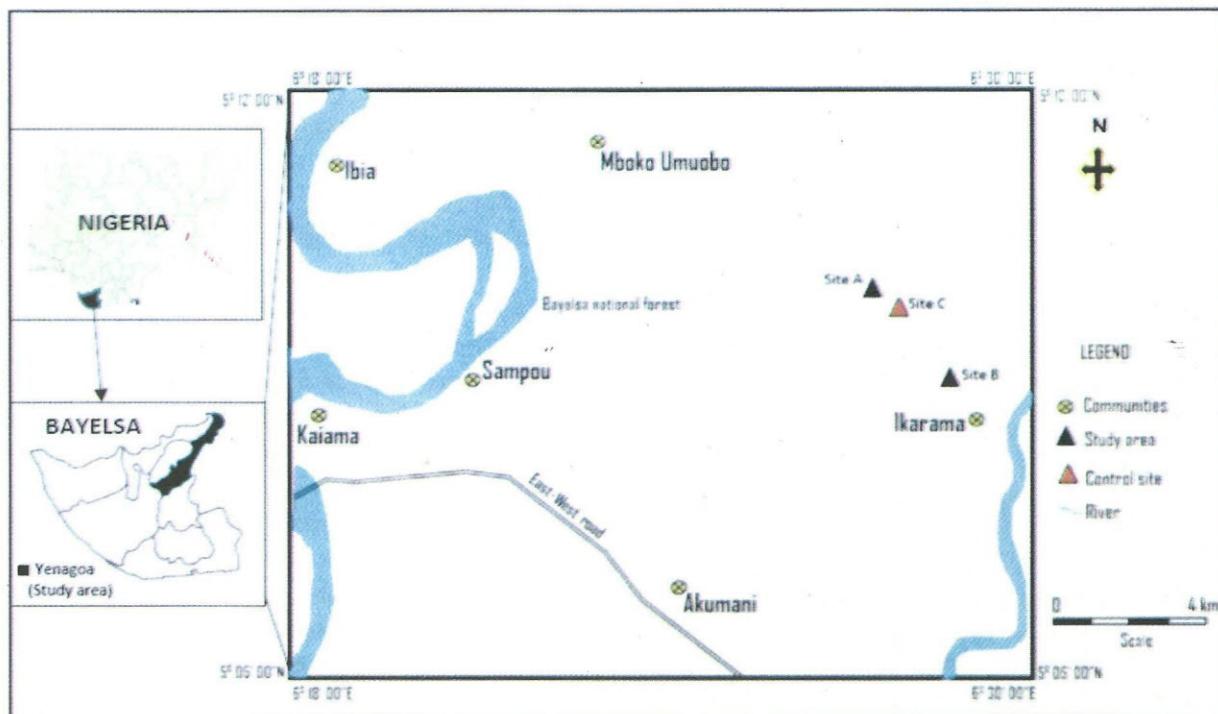


Figure 1: Map of study sites in Yenagoa L.G.A., Bayelsa State

was a farm bush ($5^{\circ} 08' 59.082''$ N and $6^{\circ} 27' 21.8448''$ E) (Figure 1). Sites A and B are owned by Shell Petroleum Development Company, and information about type of tillage remediation and age of remediation activities were obtained from the Department of Oil Pollution Control, Ministry of Environment, Bayelsa State. Accordingly, oil spills caused by

pipeline leakages occurred at Ikarama study sites in 2009 and was remediated in 2012 and 2014 at B and A sites respectively.

The type of remediation used at the study sites was entirely tillage system, where the contaminated indigenous soil was dug to about 5cm depth and thoroughly mixed. This system enhanced the mixing of the surface soil with the lower depth soil so as to dry out the impacted oil through exposure to air, and sunlight. The impacted site was elevated in such a manner that the oil from the soil drained into a small drainage dug at the side of the elevated soil to allow passage of oil to one direction for recovery. This system further increases the rate of degradation activities of the indigenous microorganism in the impacted sites, particularly as it loosened the soil pores for faster movement of the organisms.



Plate 1: Site A (1 year post-remediated site)



Plate 2: Site B (3 years post-remediated site)



Plate 3: Site C (Control/ Unpolluted Site)

Study Design/Sampling

Each site measured at 30m x 30m was divided into four sub-plots representing four replicates. Each replicate was 1m apart. Soil samples were collected randomly, once in every month for six months (June to November, 2015), using an 8.5cm² diameter bucket-type auger whose height of the bucket is 35cm from 0-20cm depth. The samples were taken to the Entomology Research Laboratory, Department of Animal and Environment Biology, University of Port Harcourt for extraction of fossorial arthropods, particularly soil microarthropods.

Composite soil sampling was done each month at 5cm depth from each study site. Samples were thoroughly mixed and put in an appropriately labelled black polyethene bag which was taken to the Laboratory for Nutrient analysis: Total Organic Carbon (TOC), Total Organic Matter (TOM), Nitrogen, Phosphorus, Potassium and Total Hydrocarbon Content (THC).

Soil Microarthropods Extraction and Identification

Modified Bukard Model of Berlesse-Tullgren funnels was used for the extraction. The extractor complex was enclosed in a metallic cabinet and it consisted of two 7-unit rows (14

units). Each extracting unit consists of a metal container with a fitted 2mm-mesh wire guaze at the base, a metallic funnel, and a 60W electric bulb above each funnel, shaded with a metal cone. The bulbs in each unit were connected to an electric source.

Extraction was done by placing the collected soil samples in the metal containers of the extracting units, labelled according to the inscription on the plastic bags with which the soil samples were collected. The metal containers were then placed above the metal funnel that opens into a labeled collecting plastic vial containing 70% ethanol for smooth collection and preservation. The electric source was switched on to light up the bulbs. Extraction commenced once the light bulbs were on as the bulbs served as a heat source, creating a temperature and humidity gradients in the soil samples. This forced active soil fauna to migrate downward and eventually fall into the collecting vials below (Andrea, 2007). Extraction lasted for seven days, followed by sorting and identification.

Identification was carried out by the use of identification keys (Krantz, 1978; Norton, 1990), pictures of past works, and those on the internet. Where necessary, compound microscope were used to aid identification.

The abundance of the identified fossorial arthropods (both less or more than 2mm size) were used to evaluate relationship of species with available nutrients.

Determination of Soil Available Nutrients

Composite soil samples were air dried at room temperature in the laboratory and then kept for organic nutrient analyses (except potassium). Some of the samples were oven-dried at 100 °C for 24hrs, after being wrapped in aluminum foil, and then ground in a mortar and sieved through a 2mm mesh size sieve. The fine particles were afterwards digested and used to analyse potassium concentration in the sample.

Total Organic Carbon in Soil

0.5g of air-dried homogenized and sieved soil sample was put in a conical refluxing flask. 10ml of standard potassium dichromate solution was added and swirl to mix, 15ml of concentrated H₂SO₄ was carefully added. The flask was connected to the condenser and

cooling water was turned on. The open end of the condenser was covered with a small beaker and the conical flask was placed on a hot plate and refluxed for one hour. The condenser was allowed to cool and rinsed down with distilled water into the conical flask. 100ml of distilled water was added after the flask was disconnected from the condenser. The flask was gently mixed by swirling and five drops of ferroine indicator was added. This was titrated with ferrous ammonium sulfate to the end point, where colour change from blue-green to violet red was observed. Both initial and final reading was recorded and organic carbon analysed to determine if the level of carbon in the soil is excess or low. In the same way, the blank sample was prepared but without the soil sample.

Organic carbon (mg/g) calculated using the formula:

Organic Carbon (mg/g) =

$$\left(\frac{18 \times C \times V}{M} \right) \times \left(1 - \frac{V_1}{V_2} \right)$$

Where: C = Concentration in Mol⁻¹ of the dichromate solution (0.166M)

V = Volume of dichromate solution used (10ml)

V_1 = Volume of titrant used (ml)

V_2 = Volume of titrant used up in the blank (ml)

M = Weight of Sample used (g)
Total Organic Matter (TOM),
was calculated by

percentage
1.724.

Nitrate-Nitrogen in Soil

10ml of sample (extracted from the soil sample) or aliquot made up of 10ml (containing between 0.1–1mg NO₃-N) was transferred with distilled water into a boiling tube. The boiling tube was put into a cool water bath and added with 2ml 30% NaCl solution. The mixture was swirled thoroughly and 10ml H₂SO₄ solution was added. Mixture was swirled again, allowed to cool and 5ml brucine sulphallic acid added. The tube was swirled to mix thoroughly and placed in a well stirred boiling water bath

maintained at 95°C. After 20 minutes, the sample was removed and immersed in a cool water bath and allowed to cool to room temperature. Absorbance was measured at 470nm using distilled water treated in the same manner as blank. A standard curve was plotted using nitrate standard solution treated in the same manner as the sample.

$$\text{Mg/LNO}_3^- = \text{mg/LNO}_3^- \times 4.43$$

Phosphorus in Soil samples

35ml (extracted from the soil sample) or an aliquot containing between 0.05 to 1.0mg phosphorus was placed in a 50ml volumetric flask.

Excessive colour in sample was removed by shaking about 50ml with 200mg activated carbon in an Erlenmeyer flask for 5 minutes and filter to remove carbon. Each batch of carbon was checked for phosphate. 10ml Vanadate-molybdate reagent was added and diluted to the mark with distilled water. A blank was prepared in which 35ml distilled water was substituted for the sample and treated in same manner as sample. After 10minutes, absorbance of the sample was measured against the blank at a wave length of 470nm. A set of serially diluted standard solutions was prepared containing 2.0, 4.0, 6.0, 8.0, 10.0, 12.0 and 16.0ml in 50ml final volume, corresponding to 0.10, 0.20, 0.30, 0.40, 0.50, 0.60 and 0.80mg P_{2O}₅ respectively, the standards were treated in the same manner as the samples and the absorbance measured against a blank. A curve is plot of absorbance against concentration.

$$\text{MgP/L} = \text{mgP} \left(\frac{\text{extrapolated from the standard curve} \times 1000}{\text{Volume of Sample (ml)}} \right)$$

Potassium in Soil Sample

Potassium in the soil sample was determined by firstly digesting the samples. Samples collected from the three sites were digested for each month for six months. Three empty 250ml beaker was weighed and recorded. Afterwards, 3g of each soil samples was poured into each beaker which was reweighed and recorded. Beakers, Nitric acid (HNO₃) and Hydrochloric acid (HCl) were placed in the fume cupboard powered by an

electric source. 10ml of HCl and 30ml of HNO_3 was poured into each beaker containing 3g of sample. It was stirred and placed in an electric cooker already turned on in the fumes cupboard. The beakers were allowed to boil and frequently checked if samples were digested. Reduction of bubbles and fumes from each beaker indicated that sample was digested. Digested samples were dropped from the heat and allowed to cool. Whatman No. 42 filter papers were folded in funnels and placed in 100ml beakers to filter digested samples. Distilled water was added to filtered samples up to 100ml of beaker and mixture was turned into labelled vials. The mixture was used to determine potassium using a flame Atomic Absorption Spectrophotometer (AAS) model (Agilent 55BSPECTRAA) which was calibrated with different concentrations of the metal of interest using the resonance wavelength of the metal and an appropriate hollow Cathode Lamp.

The concentrations of the metals were calculated using the equations:

$$\text{Metal Concentration (Mg/Kg)} = \frac{(x-y)v_2}{v_1}$$

Where x = concentration of metals obtained from atomic absorption spectrophotometer for sample (mg/l)
 y = concentration of metals obtained from atomic absorption spectrophotometer instrument for blank
 V_1 = Volume of digested sent for analysis (ml)
 V_2 = Volume sample (g)

Total Hydrocarbon Content in Soil Sample

Soil samples were air dried and sieved using a 1 μm sieve. 5g of the weighed sampled was poured into a conical flask, 10ml of n-hexane was added and the sample was extracted in a mechanical shaker. Additional 10ml of n-hexane was used for complete extraction and the extract collected in a 25ml standard flask. This was fully make up to mark with n-hexane.

This was followed by spectrophotric measurement in which a sample curvette was filled with n-hexane as the Genesis 10uv spectrophotometer.

The transmittance was adjusted to 100 percent that is zero absorbance and the wavelength was set at 425nm. The absorbance of the extracted oil was taken from the gradient of the calibration curve. The total hydrocarbon content was calculated using the formula:

$$\text{THC in mg/Kg} =$$

$$\frac{\text{Absorbance} \times \text{Volume of } n\text{-hexane} \times \text{Gradient} \times 1000}{\text{Weight of sample used}}$$

Statistical Analysis

Field and laboratory data were subjected to statistical analysis Analysis of Variance (ANOVA). Mean comparison was done using Tukey (Honestly Significant Difference) Test to assess the significant differences of soil microarthropods abundance to the level of contaminants and available nutrients among the studied sites, with level of significance set at $p > 0.05$.

RESULTS

Impact of Tillage Remediation on Soil Nutrients

The mean value of the Total Hydrocarbon (THC) content among the study sites, showed a high concentration of 237.30mg/kg (1yr-post remediated site), and least concentration of 1.40mg/kg (3yr-post remediated site) (Table 1).

The concentration of nutrients; N, P, K among the study sites, indicated that total phosphorus (P) was relatively high with 16.40mg/kg recorded at the 3yr-post remediated site and the least concentration of 5.39mg/kg of total nitrogen was

Table 1: Mean values of soil chemical parameters in the three studied sites

| PARAMETERS | SITES | | |
|-------------|------------------|-------|--------|
| | 0YR (Control) | 1YR | 3YRS |
| THC (mg/kg) | 1.401 | 237.3 | 120.12 |
| TN (%) | 6.83 | 5.39 | 5.99 |
| TP (mg/kg) | 15.41 | 14.08 | 16.40 |
| TK (mg/kg) | 7.52 | 8.63 | 7.91 |
| TOC (%) | 26.36 | 49.18 | 38.86 |
| TOM (%) | 45.46 | 84.79 | 67.01 |

Legend: THC= Total Hydrocarbon Content, TN= Total Nitrogen, TP= Total Phosphorus, TK= Total Potassium, TOC= Total Organic Carbon, TOM= Total Organic Matter, 0YR= Unpolluted/control site, 1YR= 1 year post-remediated site, 3YRS= 3 years post-remediated site

recorded at the 1yr-post remediated sites (Table 1). The results also indicated that total organic carbon and total organic matter were relatively high at 1yr- and 3yr-post remediated sites, and the least concentration occurred at the control site (Table 1).

Abundance of Soil Microarthropods in Tillage Remediated Sites

Total abundance of soil microarthropods collected from the three studied sites at the end of the period of study was recorded. A total of 625 individuals of soil micro arthropods were collected consisting of 375 recorded in the control, 88 and 162 in the 1yr –and 3yrpostremediated sites, respectively (Table 2).

Table 2: Species abundance of soil microarthropods at different months of collection

| Sampling Periods | Sites | | | |
|------------------|----------------|----------------|---------|-------|
| | 0 Year Year | 1 Year Year | 3 Years | Total |
| June | 96 | 26 | 37 | 159 |
| July | 79 | 18 | 65 | 162 |
| August | 76 | 25 | 33 | 134 |
| September | 41 | 9 | 7 | 57 |
| October | 19 | - | - | 19 |
| November | 64 | 10 | 20 | 94 |
| TOTAL | 375 | 88 | 162 | 625 |

Legend: 0YEARS= Control site (Site C),
1YEAR= 1 year post-remediated site (Site A),
3YEARS= 3 years post-remediated site (Site B)

Cryptostigmata among the mites–soil microarthropod orders was the most abundant group with a total of 263 individual species representing (42.08%) of the overall total of 625 soil microarthropods, and the least abundant was prostigmata with one species representing 0.16% (Table 3). Among other fosorial arthropods, psocoptera was the most abundant with 122 individual species, representing 19.52% and symphyla being the least with 3 individuals representing 0.48% (Table 3). *Leposcelis bostrychophila* (Order: Pscooptera), followed by *Bambara* sp. (Order: Coleoptera) were the two species that recorded the highest abundance of 122 and 33 individuals, respectively. The most abundant species among the mites were *Mixacarus* sp. and *Belba* sp. (both Cryptostigmata) which recorded 51 and 50 individuals, respectively (Table 3).

Table 3: Individual species and orders of microarthropod abundance

| SPECIES | Sites | | | |
|----------------------------------|---------------------|-----------|------------|---------------------|
| | 0 Year (Control) | 1 Year | 3 Years | Total (%) |
| Cryptostigmata | | | | |
| <i>Oppia</i> sp. | 2 | - | 1 | 3 |
| <i>Annecticarus</i> sp. | 1 | 4 | 1 | 6 |
| <i>Acheogozetes magnus</i> | 20 | 13 | 12 | 45 |
| <i>Bicrythermania</i> | | | | |
| <i>nigeriana</i> | 14 | - | - | 14 |
| <i>Belba</i> sp. | 35 | - | 15 | 50 |
| <i>Galunna nigeriana</i> | 34 | 1 | 4 | 39 |
| <i>Nothrus incavatus</i> | 5 | 1 | - | 6 |
| <i>Mixacarus</i> sp. | 30 | 5 | 16 | 51 |
| <i>Scheloribates</i> | | | | |
| <i>yorubensis</i> | 20 | 5 | 6 | 31 |
| <i>Cephalid</i> sp. | 4 | 1 | - | 5 |
| <i>Nothrus infeansis</i> | 1 | 3 | - | 4 |
| <i>Parallonothrus</i> | | | | |
| <i>nigeriensis</i> | 2 | 2 | 1 | 5 |
| <i>Atropocarus nigeriensis</i> | 3 | - | - | 3 |
| <i>Mesolophora ifeana</i> | 1 | - | - | 1 |
| Sub Total | 172 | 35 | 56 | 263 (42.08%) |
| Mesostigmata | | | | |
| <i>Macrochelid</i> sp. | 14 | 4 | 10 | 28 |
| <i>Parasitid</i> sp. | 15 | 5 | 11 | 31 |
| <i>Trachyuropoda</i> sp. | 6 | - | - | 6 |
| <i>Rhodacarus</i> sp. | 32 | 1 | 6 | 39 |
| <i>Uropoda</i> sp. | 6 | - | - | 6 |
| <i>Polyaspis</i> sp. | 17 | 1 | 4 | 22 |
| <i>Prodinichus</i> sp. | 1 | - | - | 1 |
| <i>Gamisina</i> sp. | - | - | 2 | 2 |
| <i>Iphidiomychus</i> sp. | 1 | - | - | 1 |
| Sub Total | 92 | 11 | 33 | 136(21.76) |
| Prostigmata | | | | |
| <i>Bdellidae</i> sp. | - | - | 1 | 1 |
| Sub Total | - | - | 1 | 1(0.16) |
| <i>Paronella</i> sp. | 1 | - | - | 1 |
| <i>Hypogastura brevis</i> | 1 | - | - | - |
| <i>Isotomurus palustris</i> | 16 | - | - | 2 |
| <i>Cryptophagus</i> sp. | 7 | 5 | 1 | 1 |
| <i>Folsomia candida</i> | - | - | - | 1 |
| <i>Tomocerus</i> | | | | |
| <i>lamelliferous</i> | 4 | - | - | - |
| <i>Lepidocyrtus orientalis</i> | 1 | - | - | - |
| <i>Dicyrtomma marmorata</i> | 1 | 1 | - | - |
| <i>Sminthurinus niger</i> | 1 | - | - | - |
| <i>Entomobrya</i> sp. | 1 | - | - | - |
| Sub Total | 33 | 6 | 5 | |
| Pscooptera | | | | |
| <i>Liposcelis bostrychophila</i> | 43 | 31 | 48 | |
| Sub Total | 43 | 31 | 48 | |
| Coleoptera | | | | |
| <i>Clivina fossor</i> | 3 | - | - | 2 |
| <i>Bambara</i> sp. | 13 | 5 | 15 | |
| Sub Total | 16 | 5 | 17 | |
| Isopoda | | | | |
| <i>Oniscus asellus</i> | 4 | - | - | 2 |
| Sub Total | 4 | - | 2 | |
| Diplura | | | | |
| <i>Japygid</i> sp. | 12 | - | - | - |
| Sub Total | 12 | - | - | |
| Symphyla | | | | |
| <i>Scolopendrella</i> sp. | 3 | - | - | - |
| Sub Total | 3 | - | - | |
| Grand Total | 375 | 88 | 162 | |

Legend: 0YEAR= Control site (Site C),
1YEAR= 1 year post-remediated site (Site A),
3YEARS = 3 years post-remediated site (Site B).

DISCUSSION

The present study has shown that remediation caused by tillage processes is on-going at the post-remediated sites, as observed from three perspectives; (1) reduction in the total hydrocarbon content values, (2) variation in the availability of nutrients caused by low abundance of soil microarthropods, including other fossorial arthropods, and (3) near equality of nutrients concentration at the control and three year post-remediated sites.

Okiwelu *et al.*, (2011), noted that hydrocarbon concentration caused a reduction in species abundance, and this was also observed in this present study, though in this case, it is post-remediated sites not unremediated sites where Okiwelu *et al.*, (2011) studied, indicating that reduction in species abundance also occur at on-going remediation processes in tillage post-remediation sites. This observation is corroborated with the high concentration of traces of hydrocarbon which still abound at the post-remediated sites, and most importantly as it exceeds the permissible concentration of THC which is 10mg/kg (EGASPIN, 2002). Though the THC values were high, and caused low number of individual arthropod species, a reduction in percentage concentration was also recorded particularly from the 1yr- to 3yr-post remediated sites, indicating an on-going remediation. This may have led Ayotamuno *et al.*, (2006) to report that a marked decrease in THC percentage occurred among remediated sites. Statistical analysis also led credence to this observation in this present study as the mean difference was significant at the 0.05 level ($F = 11.76$; $P = 0.01$), between THC levels of the control and that of the post-remediated sites.

The low abundance of soil microarthropods and its activities in corroboration with the activities of other soil fauna are responsible for the variation of soil nutrients recorded at the post-remediated sites in this study. There was a slight decrease in organic nutrients from the control to the post-remediated sites, with total nitrogen higher at the 3yr-post remediated site, and total organic matter higher at 1yr-post remediated site. This observation creates a

relationship of soil nutrients with soil microarthropod abundance, that the higher the relative abundance of soil microarthropods in an on-going tillage remediation site, the higher the concentration of total nitrogen, and the lower the concentrations of total organic matter and total hydrocarbon. This agrees with the positions of Imasuen *et al.*, (2014) and Abioye *et al.*, (2009) that remediation process consumes percentage organic matter in soil while remediating as a result of actions of microorganisms, which in this present study include the activities of soil microarthropods. Soil microarthropods have been known to activate the activities of soil microorganisms (Badejo *et al.*, 2004; Culliney, 2013) and contribute to the distribution of soil nutrients, therefore, a reduction in their abundance will cause a reduction in distribution of soil nutrients. This is the situation in this present study, with the concentration of total phosphorus and potassium in both the control and 3yr-post remediated sites nearly equal, indicating that remediation is on-going. The implications of these are in line with Schowalter (2011) that fossorial arthropods (microarthropods inclusive) have the capacity to control nutrients availability for and perhaps uptake by plants.

CONCLUSION

The present study has indicated the relationship between soil microarthropod's abundance and availability as well as distribution of nutrients in a post-remediated tillage enhanced remediation from crude oil soil contamination. The relationship was more at the 3yr-post remediation sites. Also, this study has shown that the application of tillage remediation, reduces total hydrocarbon and total organic matter concentration with increase in soil microarthropods with time, indicating that the remediating process is on-going with much consumption of organic matter. The study indicates that the use of tillage remediation will require longer time of recovery from crude oil contamination, thus further studies on the effect of a combination of tillage and other artificial remediation should be conducted.

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