*Geosystem Engineering* **14**(2), 51-58 (June 2011)

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The Korean Society for Geosystem Engineering
Korean Society for Rock Mechanics
The Korean Institute of Resources Recycling

Research Paper

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# Bioconversion of Crude Oil Production Sludge into Soil Conditioner Using Sawdust as Organic Amendment

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**ABSTRACT:** Nigeria is a major oil producer in Africa and the World, with significant oil exploration and production activities. These vast oil activities pose a challenge in disposal of oily sludge. The objective of this study was to adopt the principles of biotechnological wastes - to - wealth conversion for the utilization of abundant oily sludge waste. Various sawdust/oily sludge (SD/OS) ratios were used for composting for 21 weeks with sawdust (SD), oily sludge (OS) and untreated soil used as controls. Total heterotrophic bacterial count for SD/OS ratios used ranged between 7.4 and 17.4 x $10^6$ cfu/g and between 6.2 and 18.4 x $10^6$ cfu/g for controls. Hydrocarbon utilizing bacterial counts ranged between 5.9 and 9.0 x $10^6$ cfu/g for SD/OS ratios and between 5.4 and 5.8 x $10^6$cfu/g for controls while total fungal counts for SD/OS ratios used ranged between 4.5 and 5.0 x $10^7$cfu/g and between 3.25 and 5.50 x $10^7$ cfu/g for controls. Hydrocarbon utilizing fungal counts ranged between 3.50 and 4.25 x $10^7$ cfu/g for SD/OS ratios and between 3.00 and 5.25 x $10^2$cfu/g for controls. Predominant bacterial genera isolated were *Micrococcus, Flavobacterium, Pseudomonas, Acinetobacter* and *Staphylococcus* while fungal genera were *Aspergillus, Penicillium, Saccharomyces* and *Candida*. Nutrient levels for nitrogen, potassium, phosphorus, magnesium, iron and zinc reduced between weeks 0 – 21. Microbial counts increased between weeks 0 and 7 and decreased between weeks 14 and 21 of composting for SD/OS ratios, SD and OS. SD/OS ratios 1:1, 4:1, 8:1, 16:1 caused the most positive significant effects on plant growth. This research shows that oily sludge from oil activities can be converted to soil conditioner to enhance agricultural productivity and thus ensure food security.

**Key words:** Bioconversion, Oily sludge, Soil conditioner, Sawdust, Microorganisms

Received February 13, 2011; Revised February 22, 2011; Accepted April 13, 2011

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## INTRODUCTION

One of the major problems faced by oil industries worldwide including those operating within the Niger Delta Region, Nigeria is the disposal of oily sludge generated during the transfer, storage and processing of crude oil. The term "oily sludge" is often used to denote all the materials, which may settle at the bottom of crude oil storage tanks commonly referred to as 'bottom sediment and water" (BS&W) and is made up of sand, debris, and chemical compounds resulting from the coagulation and oxidation of the hydrocarbons in the oil and water mixtures. The result of separation of crude oil and water is a heavy hazardous sludge (World Bank, 1995).

The Nigerian economy is highly dependent on crude oil, about 95% of the crude oil produced is from the Niger Delta region with the operations of major multinational oil companies like Shell Petroleum Development Company (SPDC), Exxon Mobil, Totalfinaelf, Nigerian Agip Oil Company limited (NAOC), ChevronTexaco, etc. Improper disposal of oily sludge which is a major challenge in the Niger Delta region of Nigeria leads to environmental pollution, particularly soil contamination and poses serious threats to surface and ground water. Many of the components of oily sludge are known to be carcinogenic and potent immunotoxicants (Propst *et al.*, 1999). Bioaccumulation of the components of petroleum production wastes (oily sludge and effluents) in aquatic resources and biotoxicity to humans in the Niger Delta region have extensively been reported (Udotong, 1995, 2000; Udotong, 2004).

Among the many techniques employed to decontaminate sites polluted by oily sludge is farming on the land or land treatment whereby the oil and debris is spread over an area of land to increase the surface area for environmental factors and microorganisms to act on it. This approach to reclaiming contaminated land requires a large expanse of land depending on the quantity of oily sludge to be treated and also increases the threat to surface and ground water (Bardeau *et al.*, 1997). According to Huesemann and Truex (1996), the simplest method of bioremediation to implement is the one that utilizes natural attenuation, where contaminated sites are only monitored for contaminant concentration to assure regulators that natural

processes of contaminant degradation are active. Composting of oily sludge will utilize smaller space than land farming while utilizing natural attenuation processes to enhance contamination biodegradation rates.

Different wastes streams of oil & gas exploration & production activities (E&P) from various sources have peculiar handling and management approaches (Odejimi and Udotong, 2004). Oily sludge and oil contaminated wastes from oil & gas E&P activities require innovative approach for its proper disposal. Most recently is the need for wastes diversion studies utilizing biotechnological "wastes – to – wealth" conversion approaches where wastes are converted to useful products. In view of the abundance of this waste stream in the Niger Delta region due to oil exploration and production activities, and the huge agricultural potentials of the region, it is imperative to device a biotechnological and an environmentally-friendly management approach to convert these abundant wastes to soil conditioner to ensure food security.

Till date, large scale bioremediation of oily sludge by the multinational oil companies are not reported. This bioremediation project was therefore conducted at a pilot plant scale using saw dust as organic amendment, with a view to testing the results at a large scale. The efficiency of the produced soil conditioner was tested in the field using *Zea mays* as a test crop.

## MATERIALS AND METHODS

### Sample collection

The oily sludge was obtained from Shell Petroleum Development Company (SPDC), Port Harcourt, Rivers State, Nigeria. Sawdust was used as organic amendment source and was collected from Ikot Ekpene Timber Market in Ikot Ekpene Local Government Area, Akwa Ibom State, Nigeria.

### Compost mixture and controls

The compost mixtures were sawdust plus oily sludge (SD/OS) mixed at the following ratios; 1:1, 4:1, 8:1, 16:1,1:4, 1:8 and 1:16 using weight/weight basis. Three (3) control experiments were set up using raw sawdust, oily sludge and untreated agricultural soil. The total weight of each of the compost mixtures were about five kilogramme (5 kg).

### Composts treatments

Each of the nine (9) composts heaps / windrows (6 composts mixtures and 3 controls) were turned and watered at intervals until the different composts heaps stabilized after 21 weeks of composting. The turning and watering were carried out at 3 days interval for the first two weeks and at 7 days interval for the rest of the composting period. Air and compost temperature were taken before each turning and windrows were kept under shed to minimize nutrient losses.

### Sampling and sample analyses

Samples of the raw sawdust, oily sludge and agricultural soil (controls) and samples from each of the different compost mixtures (1:1, 4:1, 8:1, 16:1, 1:4, 1:8 and 1:16) were collected for microbiological and physicochemical analysis at day 1 (first day of composting), end of week 7, end of week 14 and end of week 21.

### Microbiological analyses

Samples were analyzed for total heterotrophic bacterial counts (THBC), total fungal counts (TFC) and total hydrocarbon utilizing microbial counts (HUM). THBC and TFC were determined by spread plate method using nutrient agar and Sabaurud Dextrose Agar (SDA), respectively while HUM were determined using Zagic and Supplisson's mineral salt medium containing crude oil as sole source of carbon and energy (Zagic and Supplisson, 1972).

### Serial dilution

Ten-fold Serial dilutions of the samples were made according to the methods of Collins and Lyne (1976) and Harrigan and McCance (1976).

### Inoculation and incubation

One millilitre of appropriate ten-fold serial dilutions of the sample were inoculated onto appropriate nutrient media in triplicates using pour plate methods of Collins and Lyne (1976) and Harrigan and McCance (1976) and spread plates methods of Demain and Davies (1999). Inoculated plates were incubated at 28±2℃ for 18-24 hours and 48-72 hours for the enumeration of total heterotrophic bacteria and fungi, respectively. Visible discrete colonies on incubated plates were counted and expressed as colony forming units per gram (cfu/g) of samples.

### Maintenance of pure culture

Discrete Colonies were purified by repeated sub-culture unto appropriate nutrient media. Pure cultures were preserved on appropriate nutrient media slants and stored in the refrigerator (4℃±2℃) and at ambient temperature (28℃±2℃) for further tests.

### Characterization and identification of microbial isolates

Pure cultures of microbial isolates were identified based on cultural parameters, microscopic techniques and biochemical tests including carbohydrate utilization as describe by Cruickshank *et al.* (1975). Identification of the bacterial isolates was accomplished by comparing the characteristics of the cultures with that of known taxa using Bergey's Manual of Determinative Bacteriology (Holt *et al.*, 1994). Characterization and identification of fungal isolates was done according to Domsch *et al.* (1980) and Barnett and Hunter (1987).

### Physicochemical Analysis

Temperature was determined with mercury-in-glass thermometer while pH was determined with the pH meter. Nitrogen was determined using the Macro-Kjeldahl method while available phosphorus, potassium, organic matter content, moisture content and total petroleum hydrocarbon were determined by the methods of Association of Official Analytical Chemists (A.O.A.C., 1984).

**Effects of the produced soil conditioner on plant growth/ performance**

After 21 weeks of composting, 500 g of the produced soil conditioners were weighed and mixed with 1 kg of soil (top soil, obtained from 10 cm depth). The soil and soil conditioner mixtures were introduced into poly bags and moistened with water. Corn (*Zea mays*) seeds were planted, four (4) in each poly bag. After germination thinning was done on each bag to trim down the number of maize plant to three (3) per poly bag. The planting was done in duplicate and the plants were watered daily. Plants height and stem girth were taken after germination at 3 days interval.

## RESULTS AND DISCUSSION

Microbial counts increased at week 7 and reduced at weeks 14 and 21 (Tables 1 – 4). Predominant bacterial isolates from the compost mixtures were characterized and identified as species of *Micrococcus, Acinetobacter, Flavobacterium, Staphylococcus, Pseudomonas, Bacillus* and *Actinomyces* (Table 5). While species of *Aspergillus, Penincillium* and *Rhizopus* were the predominant fungal isolates (Table 6), only species of *Saccharomyces* and *Candida* (Table 7) were the yeasts isolates from the compost mixtures. Available nitrogen, phosphorus and potassium levels decreased for all samples in this study (Tables 8 – 10). Reduction in the organic matter content and moisture content levels were observed in this study (Tables 11 – 12). Total petroleum hydrocarbon (TPH) levels decreased during the composing, SD/OS ratio 16:1 had the highest TPH reduction level of 90% while ROS (control) had the lowest TPH reduction level of 53% (Table 13). The temperature values ranged between 28℃ and 30℃ for atmospheric and between 37℃ and 55℃ for compost (Table 14) while the pH ranged between slightly alkaline to slightly acidic (Table 15). Table 16 presents the stem circumference of corn plants measured some days after planting on the soil conditioners with various ratios of oily sludge and sawdust. The produced soil conditioners with three (3) different sawdust: oily sludge ratios were observed to have significant effect ($P>0.05$) on *Zea mays* plants growth using plants height and stem girth (Figs. 1 and 2).

A major component of oily sludge and oil contaminated soil that threatens soil utility for agriculture (crop production or aquaculture in wetland soils) is crude oil and its components (Essien and Udotong, 1999; Udotong and Akpanekon, 2007a & b). To reduce the oil content of the sludge and increase the surface area for the microorganisms to act on the oil, organic amendment source was introduced. Again, sawdust or biomass is abundant in the Niger Delta region as against chicken droppings or cow dung that has been proposed for use (Ijah and Okang, 1993).

A rapid increase in total microbial count at week 7 observed in this study has been reported (Wolter *et al.*, 1997). This increase in microbial count was most likely due to favorable conditions established by the addition of organic amendment (sawdust), frequent aeration and moistening (Tables 1 – 4).The decrease in microbial count from week 14 of the composting was likely due to the reduction of favorable condition which had been established before, while microbial count for soil (control) was observed to be relatively stable, there was no significant increase in microbial count through out composting period.

Total hydrocarbon utilizing bacterial and fungal counts increased at week 0 and 7 in response to high level of total petroleum hydrocarbon (Table 3 and 4). The hydrocarbon utilizing bacteria were in abundance between week 1 and week 7. This was due to the high level of TPH in the sludge as reported by Admon *et al.* (2001). The hydrocarbon utilizing bacteria

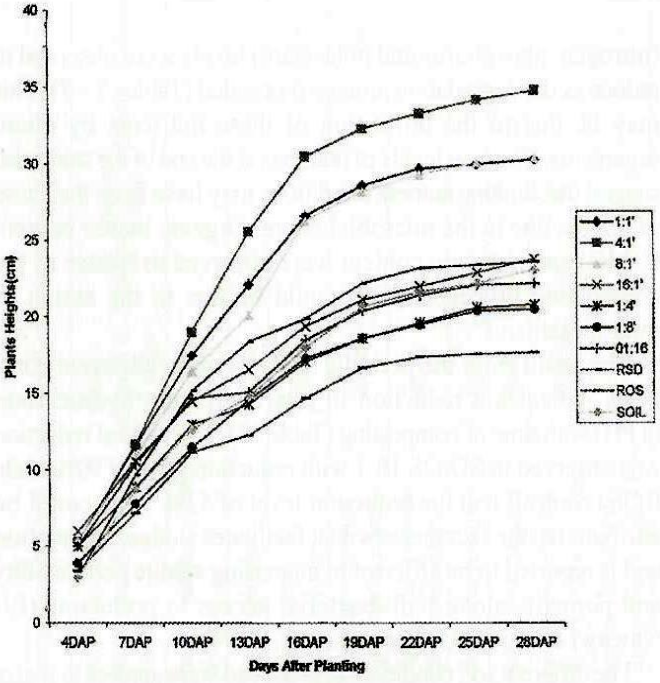


**Fig. 1.** Height of maize plants as influenced by different levels of compost treatments.


**Fig. 2.** Height of maize plants treated with soil conditioner 1:16 with the control at 2 weeks after planting (Note: OS = Oily sludge (Control); SD = Saw Dust (Control); 2WAP = 2 weeks after planting; Soil = Control).

**Table 1.** Heterotrophic bacterial count (x$10^7$ cfu/g) of compost samples during composting process.

| Compost samples | Weeks of composting | | | | Mean ± SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 10.8 | 12.9 | 9.7 | 3.7 | 9.3 ± 0.43 |
| 4:1 | 18.4 | 23.7 | 14.2 | 4.0 | 15.1 ± 0.72 |
| 8:1 | 20.0 | 24.8 | 16.2 | 4.3 | 16.3± 0.76 |
| 16:1 | 21.2 | 26.0 | 18.2 | 4.1 | 17.4 ± 0.82 |
| 1:4 | 8.5 | 10.0 | 9.3 | 3.1 | 7.7 ± 0.27 |
| 1:8 | 7.8 | 10.4 | 8.7 | 3.6 | 7.6 ± 0.25 |
| 1:16 | 7.2 | 9.8 | 7.9 | 4.7 | 7.4 ± 0.18 |
| RSD | 19.6 | 24.0 | 15.1 | 4.7 | 15.9 ± 0.72 |
| ROS | 6.3 | 8.7 | 6.9 | 2.9 | 6.2 ± 0.21 |
| SOIL | 17.2 | 18.9 | 18.7 | 18.8 | 18.4 0.07 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw sawdust. ROS; Raw oily sludge

**Table 2.** Total fungal count (x10 cfu/g) of compost samples during composting process.

| Compost samples | Weeks of composting | | | | Mean/SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 5.0 | 6.0 | 5.0 | 3.0 | 4.75 ± 1.09 |
| 4:1 | 6.0 | 6.0 | 5.0 | 4.0 | 5.00 ± 0.87 |
| 8:1 | 5.0 | 6.0 | 4.0 | 3.0 | 4.5 ± 1.12 |
| 16:1 | 6.0 | 5.0 | 4.0 | 3.0 | 4.5 ± 1.72 |
| 1:4 | 5.0 | 6.0 | 5.0 | 4.0 | 5.0 ± 0.71 |
| 1:8 | 6.0 | 6.0 | 5.0 | 3.0 | 5.0 ± 1.22 |
| 1:16 | 5.0 | 6.0 | 4.0 | 3.0 | 4.5 ± 1.12 |
| RSD | 4.0 | 6.0 | 4.0 | 3.0 | 4.25 ± 1.09 |
| ROS | 3.0 | 5.0 | 3.0 | 2.0 | 3.25 ± 1.09 |
| SOIL | 6.0 | 5.0 | 6.0 | 5.0 | 5.50 ± 0.5 |

Note: Samples contain sawdust and Oily Sludge (SD + OS) in different ratios. RSD; Raw Sawdust. ROS; Raw oily sludge

**Table 3.** Hydrocarbon utilizing bacterial count (x$10^6$ cfu/g) of compost samples during the composting process.

| Compost samples | Weeks of composting | | | | Mean/SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 7.2 | 10.2 | 9.2 | 3.0 | 7.4 ± 0.28 |
| 4:1 | 7.8 | 10.9 | 10.1 | 3.2 | 8.0 ± 0.30 |
| 8:1 | 8.4 | 11.2 | 10.3 | 3.5 | 8.4 ± 0.30 |
| 16:1 | 8.7 | 12.5 | 11.0 | 3.9 | 9.0 ± 0.33 |
| 1:4 | 6.2 | 7.8 | 6.9 | 2.7 | 5.9 ± 0.19 |
| 1:8 | 6.8 | 8.9 | 7.1 | 2.9 | 6.4 ± 0.32 |
| 1:16 | 6.6 | 9.4 | 8.9 | 2.8 | 6.9 ± 0.26 |
| RSD | 6.0 | 6.5 | 5.8 | 3.1 | 5.4 ± 0.13 |
| ROS | 6.3 | 6.9 | 6.0 | 3.8 | 5.8 ± 0.12 |
| SOIL | 5.6 | 5.1 | 5.4 | 5.5 | 5.4 ± 0.02 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw Sawdust. ROS; Raw oily sludge

**Table 4.** Hydrocarbon utilizing fungal count (x$10^7$ cfu/g) of compost samples during composting.

| Compost samples | Weeks of composting | | | | Mean/SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 4.0 | 5.0 | 4.0 | 2.0 | 3.75 ± 1.09 |
| 4:1 | 5.0 | 5.0 | 4.0 | 3.0 | 4.25 ± 0.83 |
| 8:1 | 4.0 | 5.0 | 3.0 | 3.0 | 3.75 ± 0.83 |
| 16:1 | 5.0 | 4.0 | 3.0 | 2.0 | 3.50 ± 1.12 |
| 1:4 | 4.0 | 5.0 | 4.0 | 3.0 | 4.00 ± 0.71 |
| 1:8 | 5.0 | 5.0 | 4.0 | 2.0 | 4.00 ± 1.22 |
| 1:16 | 4.0 | 5.0 | 3.0 | 2.0 | 3.50 ± 1.12 |
| RSD | 4.0 | 5.0 | 4.0 | 3.0 | 4.00 ± 0.71 |
| ROS | 3.0 | 4.0 | 3.0 | 2.0 | 3.00 ± 0.71 |
| SOIL | 5.0 | 5.0 | 6.0 | 5.0 | 5.25 ± 0.43 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw sawdust. ROS; Raw oily sludge

decreased thereafter at week 14 and 21. This could be due to decomposition of hydrocarbon in the sludge. *Actinomyces, Flavobacterium* and *Pseudomomas* were observed to flourish within the first 7 weeks and their positive correlation with TPH levels. While the microbial counts of *Flavobacterium* and *Actinomyces* were low between week 7 and 14 due to limited nutrients, microbial counts of *Micrococcus, Bacillus* and *Acinetobacter* were high within the period. *Staplylococcus aureus* was observed at week 21 of the composting. The low relative abundance and lack of response by *Staph. aureus* to petroleum concentration indicate that they did not contribute significantly to the TPH degradation, but may have contributed to degradation of the compost at some level. Predominant fungal genera within the first 14 weeks of composting were *Aspergillus* and *Penicillium. Candida* and *Saccharomyces* were observed to be relatively low and stable throughout the composting period except for a temporary increase at week 21. This relatively stable fungal count / activity during the composting process may have been because the identified fungi cannot utilize the crude oil for growth and reproduction and therefore are not crude oil degraders. In the course of this study, nutrient (nitrogen, phosphorus and potassium) levels were observed to reduce as the degradation process proceeded (Tables 5 – 7). This may be due to the utilization of these nutrients by micro organisms. The low levels of nutrients at the end of the study also suggest that limiting nutrient conditions may have been the cause of the decline in the microbial count. Organic matter content (OMC) and moisture content were observed to reduce as the composting proceeded; this could be due to the action of microorganisms.

The result from the periodic analysis of the different composts indicates a reduction in total petroleum hydrocarbon (TPH) with time of composting (Table 13). The highest reduction was observed in SD/OS 16:1 with reduction level of 90% while ROS (control) had the reduction level of 53%. This could be attributed to the fact that sawdust facilitates sludge degradation and is reported to be efficient in increasing sludge permeability and porosity, along with bacterial access to pollutants (El-Nawawi *et al.,* 1992; Hiebert *et al.,* 1994).

The different soil conditioners produced were applied to maize (*Zea mays)*plants and it was observed that soil conditioners of sawdust/oily sludge ratios 1:1, 4:1, 8:1 and 16:1 had the significant effect

**Table 5.** Morphological and biochemical characterization and identification of bacterial isolates.

| Isolates Code | Nature of colony formation on the plate | Gram's reaction & cell shape | Motility | Spore stain | Indole | Catalase | Coagulase | Oxidase | MR-test | V-p test | Urease | Citrate | Gelatin liquifaction | CARBOHYDRATE UTILIZATION TEST | | | | | Probable organism |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | Glucose | Sucrose | Lactose | Galactose | Mannitol | |
| B1 | Smooth rounded yellow colonies | + Cocci | - | - | - | + | - | + | - | - | + | + | - | AG | A | AG | AG | AG | *Micrococcus sp* |
| B2 | Orange colonies | + Cocci | - | - | + | + | + | - | - | - | + | + | | AG | AG | A | AG | AG | *Staphylococcus sp* |
| B3 | Irregular and creamy colonies | + Rods | + | + | - | + | - | - | - | + | + | + | - | AG | A | A | AG | A | *Bacillus sp* |
| B4 | Flat creamy colonies with irregular edges | - Rods | - | - | - | + | - | + | - | + | - | - | + | AG | AG | A | AG | - | *Flavobacterium sp* |
| B5 | Irregular flat colonies with serrated edges | - Rods | - | - | + | + | - | - | + | - | - | - | + | AG | A | - | A | AG | *Actinomyces sp* |
| B6 | Pale colored colonies | - Rods | + | - | - | + | - | + | - | - | + | + | + | A | AG | AG | A | A | *Pseudomonas sp* |
| B7 | Smooth pink colonies | - Rods | - | - | + | + | - | - | + | - | - | - | + | AG | AG | AG | AG | AG | *Escherichia sp* |
| B8 | Creamy, irregular flat colonies with waxy edges | + Rods | + | + | - | + | - | - | - | + | + | + | + | AG | AG | AG | AG | AG | *Bacillus megaterium* |
| B9 | Irregular flat creamy colonies with rough edges | - Rods | - | - | + | + | - | - | + | - | - | - | + | AG | A | AG | AG | G | *Acinetobacter sp* |

Note: MAC = McConkay agar; NA = Nutrient agar; + = Positive reaction; - = Negative reaction; A = Acid production. G = Gas production; AG = Acid & gas production

**Table 6.** Morphological characterization and identification of fungal isolates.

| Isolates codes | Color of aerial hyphae | Color of substrate hyphae | Nature of hyphae | Shape & kind of asexual structure | Presence of special structure | Appearance of sporangiophore or conidiophore | Characteristics of spore head | Probable organism |
|---|---|---|---|---|---|---|---|---|
| F1 | Green | Brown | Septate, multi-nucleate | Oval greenish conidia | Foot cell present | Long, erect, non-septate | Multinucleate vesicle with broom-like group of sterigmata, bearing long chains of conidia | *Aspergillus sp* |
| F2 | Green | Brown | Septate & branched | Oval conidia | Foot cell absent | Simple, Long, erect conidiophore | Assymetrical & multinucleate | *Penicillum sp* |
| F3 | Black | Brown | Non-septate | Oval shaped conidia globose | Foot cell present | NA | NA | *Rhizopus sp* |

**Table 7.** Morphological characterization and identification of yeasts isolates.

| Isolates Code | Gram's reaction | Color of colony on SDA | Size of colony on SDA | Elevation of colony on SDA | Outline of colony on SDA | Cell shape | Growth on 5% glucose | Growth on 10% NaCl | Formation of germ tube | Ascospore formation | Growth at 37℃ | Formation of blastospore | CARBOHYDRATE UTILIZATION TEST | | | | | | | Probable organism |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Arabinose | Inositol | Sucrose | Galactose | Mannitol | Xylose | Maltose | |
| Y1 | + | Light brown | 3-5 mm | Raised | Entire | Oval, budding | + | + | + | - | + | + | - | - | + | + | - | - | - | *Candida sp* |
| Y2 | + | Cream | 1-4 | Raised | Entire | Oval | - | + | - | + | + | + | - | - | + | + | - | - | + | *Saccharomyces sp* |

**Table 8.** Nitrogen levels (mg/100g) during the composting process.

| Compost sample | Weeks of composting | | | | Mean ± SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 0.28 | 0.25 | 0.23 | 0.21 | 0.24 ± 0.03 |
| 4:1 | 0.24 | 0.20 | 0.17 | 0.15 | 0.19 ± 0.03 |
| 8:1 | 0.26 | 0.23 | 0.18 | 0.15 | 0.21 ± 0.04 |
| 16:1 | 0.26 | 0.22 | 0.17 | 0.15 | 0.20 ± 0.04 |
| 1:4 | 0.24 | 0.22 | 0.20 | 0.17 | 0.21 ± 0.03 |
| 1:8 | 0.28 | 0.26 | 0.24 | 0.21 | 0.25 ± 0.02 |
| 1:16 | 0.28 | 0.25 | 0.22 | 0.20 | 0.24 ± 0.30 |
| RSD | 0.24 | 0.22 | 0.19 | 0.16 | 0.20 ± 0.03 |
| ROS | 0.28 | 0.26 | 0.24 | 0.21 | 0.25 ± 0.03 |
| SOIL | 0.14 | 0.13 | 0.13 | 0.12 | 0.13 ± 0.01 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw Sawdust. ROS; Raw oily sludge

**Table 9.** Phosphorous levels (mg/100g) during the composting process.

| Compost sample | Weeks of composting | | | | Mean ± SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 3.15 | 2.86 | 1.42 | 0.61 | 2.01 ± 1.04 |
| 4:1 | 3.72 | 2.45 | 1.42 | 0.60 | 2.05 ± 1.17 |
| 8:1 | 3.74 | 2.47 | 1.20 | 0.58 | 2.00 ± 1.22 |
| 16:1 | 3.74 | 2.38 | 1.39 | 0.54 | 2.01 ± 1.19 |
| 1:4 | 5.41 | 3.42 | 2.21 | 1.66 | 2.44 ± 1.84 |
| 1:8 | 5.97 | 3.39 | 2.24 | 1.90 | 2.63 ± 2.01 |
| 1:16 | 5.79 | 3.43 | 2.41 | 1.60 | 2.60 ± 1.98 |
| RSD | 4.73 | 3.77 | 1.79 | 0.86 | 2.79 ± 1.54 |
| ROS | 5.77 | 4.63 | 2.87 | 1.88 | 3.54 ± 1.85 |
| SOIL | 1.24 | 1.23 | 1.23 | 1.22 | 1.23 ± 0.01 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw sawdust. ROS; Raw oily sludge

**Table 10.** Potassium levels (mg/100g) during the composting process.

| Compost sample | Weeks of composting | | | | Mean ± SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 142.70 | 124.60 | 113.10 | 91.50 | 177.98 ± 18.57 |
| 4:1 | 122.30 | 144.70 | 81.38 | 72.01 | 105.10 ± 29.67 |
| 8:1 | 202.90 | 140.40 | 107.10 | 77.14 | 131.89 ± 46.71 |
| 16:1 | 178.20 | 134.70 | 110.70 | 92.10 | 128.93 ± 32.21 |
| 1:4 | 138.90 | 97.10 | 64.15 | 56.60 | 89.19 ± 32.50 |
| 1:8 | 148.70 | 110.20 | 87.76 | 60.15 | 101.70 ± 32.41 |
| 1:16 | 144.00 | 113.11 | 90.41 | 65.71 | 103.31 ± 28.86 |
| RSD | 147.70 | 137.90 | 115.10 | 78.69 | 119.85 ± 26.54 |
| ROS | 136.80 | 109.11 | 75.90 | 59.47 | 95.32 ± 29.89 |
| SOIL | 24.15 | 23.12 | 21.97 | 20.10 | 22.34 ± 1.50 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw sawdust. ROS; Raw oily sludge

**Table 11.** Organic matter content (omc) levels (mg/100g) during composting process.

| Compost sample | Weeks of composting | | | | Mean ± SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 70.70 | 62.40 | 59.10 | 44.20 | 59.1 ± 18.56 |
| 4:1 | 80.50 | 60.95 | 56.40 | 48.30 | 61.54 ± 11.85 |
| 8:1 | 75.67 | 66.40 | 60.70 | 50.45 | 63.30 ± 9.14 |
| 16:1 | 77.04 | 66.80 | 59.70 | 49.10 | 63.20 ± 10.19 |
| 1:4 | 53.72 | 49.40 | 35.20 | 29.40 | 41.90 ± 9.96 |
| 1:8 | 48.50 | 46.55 | 38.80 | 26.30 | 40.00 ± 8.72 |
| 1:16 | 44.46 | 40.75 | 39.40 | 30.70 | 38.80 ± 5.04 |
| RSD | 80.72 | 74.10 | 67.80 | 56.20 | 69.7 ± 9.04 |
| ROS | 35.35 | 31.55 | 29.70 | 28.55 | 31.30 ± 2.60 |
| SOIL | 63.08 | 59.82 | 50.10 | 45.20 | 54.6 ± 7.21 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw sawdust. ROS; Raw oily sludge

**Table 12.** Moisture content (MC) levels (%) during composting process.

| Compost sample | Weeks of composting | | | | Mean ± SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 49.30 | 37.60 | 19.70 | 15.80 | 30.60 ± 13.57 |
| 4:1 | 29.50 | 26.05 | 18.20 | 13.70 | 21.90 ± 6.24 |
| 8:1 | 24.33 | 21.60 | 16.10 | 12.55 | 18.65 ± 4.62 |
| 16:1 | 22.96 | 19.20 | 13.20 | 10.90 | 16.60 ± 4.78 |
| 1:4 | 46.29 | 19.60 | 12.70 | 10.60 | 22.30 ± 14.25 |
| 1:8 | 51.50 | 19.45 | 16.60 | 13.70 | 25.31 ± 15.26 |
| 1:16 | 65.54 | 12.25 | 8.72 | 5.30 | 23.00 ± 24.71 |
| RSD | 19.29 | 25.90 | 19.96 | 13.80 | 19.74 ± 4.29 |
| ROS | 64.65 | 16.45 | 12.76 | 9.45 | 25.83 ± 22.55 |
| SOIL | 16.92 | 18.00 | 18.90 | 17.20 | 17.76 ± 0.77 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw sawdust. ROS; Raw oily sludge

**Table 13.** Total petroleum hydrocarbon (TPH) levels (mg/100g) during composting process.

| Compost sample | Weeks of composting | | | | Mean±SD |
|---|---|---|---|---|---|
| | 0 | 7 | 14 | 21 | |
| 1:1 | 780 | 324 | 210 | 108 | 86 |
| 4:1 | 630 | 264 | 170 | 80 | 87 |
| 8:1 | 670 | 294 | 148 | 72 | 89 |
| 16:1 | 604 | 242 | 178 | 60 | 90 |
| 1:4 | 1442 | 954 | 684 | 462 | 68 |
| 1:8 | 1460 | 998 | 701 | 497 | 66 |
| 1:16 | 1600 | 1009 | 892 | 565 | 65 |
| RSD | NIL | NIL | NIL | NIL | NA |
| ROS | 2700 | 1870 | 1570 | 1268 | 53 |
| SOIL | NIL | NIL | NIL | NIL | NA |

Note: Samples contain Sawdust and oily sludge (SD + OS) in different ratios. RSD; Raw sawdust. ROS; Raw oily sludge. NIL; Not detected. ND; Not applicable.

(P>0.05) on plants growth (Fig. 1). This observation is due to the right proportions of the compost materials. Sawdust/Oily sludge 1:4, 1:8 and 1:16 had no significant effect in the plants growth; this is due to the lowest proportion of sawdust to oil sludge that was applied.

**Table 14.** Compost and atmospheric temperature (℃) during composting.

| Compost sample | Weeks of composting | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | | 7 | | 14 | | 21 | |
| | Comp | Atmos | Comp | Atmos | Comp | Atmos | Comp | Atmos |
| 1:1 | 38 | 29 | 55 | 30 | 49 | 29 | 38 | 28 |
| 4:1 | 37 | 28 | 54 | 30 | 48 | 28 | 37 | 29 |
| 8:1 | 37 | 28 | 53 | 29 | 48 | 28 | 37 | 28 |
| 16:1 | 38 | 29 | 54 | 29 | 49 | 29 | 39 | 28 |
| 1:4 | 39 | 29 | 52 | 30 | 46 | 28 | 37 | 20 |
| 1:8 | 38 | 28 | 54 | 29 | 47 | 29 | 38 | 29 |
| 1:16 | 39 | 28 | 54 | 30 | 47 | 29 | 38 | 29 |
| RSD | 38 | 29 | 51 | 30 | 47 | 28 | 37 | 28 |
| ROS | 39 | 28 | 50 | 29 | 45 | 28 | 39 | 28 |
| SOIL | 30 | 29 | 31 | 29 | 30 | 28 | 30 | 28 |

Note: Comp; Compost temperature; Atm; Atmospheric temperature

**Table 15.** Levels of pH at different compost treatments during composting process.

| Compost sample | Weeks of composting | | | |
|---|---|---|---|---|
| | 0 | 7 | 14 | 21 |
| 1:1 | 7.3 | 7.4 | 7.2 | 6.5 |
| 4:1 | 7.4 | 7.6 | 7.2 | 6.8 |
| 8:1 | 7.4 | 7.6 | 7.2 | 6.7 |
| 16:1 | 7.2 | 7.7 | 7.3 | 6.7 |
| 1:4 | 7.3 | 7.8 | 7.5 | 6.9 |
| 1:8 | 7.4 | 7.6 | 7.3 | 6.9 |
| 1:16 | 7.4 | 7.8 | 7.4 | 6.8 |
| RSD | 7.2 | 7.4 | 7.1 | 6.4 |
| ROS | 7.3 | 7.8 | 7.3 | 6.8 |
| SOIL | 6.8 | 6.5 | 6.7 | 6.5 |

Note: Samples contain Sawdust and Oily Sludge (SD + OS) in different ratios. RSD; Raw sawdust. ROS; Raw oily sludge

**Table 16.** Stem circumference (cm) at different periods of growth (days after planting, DAP)

| Sample | 4 | 7 | 10 | 13 | 16 | 19 | 22 | 25 | 28 | Mean ± SD |
|---|---|---|---|---|---|---|---|---|---|---|
| 1:1 | 1.1 | 1.4 | 1.5 | 1.7 | 1.8 | 2.0 | 2.2 | 2.3 | 2.4 | 1.82 ± 0.42 |
| 4:1 | 1.1 | 1.4 | 1.5 | 1.7 | 1.8 | 2.0 | 2.2 | 2.3 | 2.4 | 1.82 ± 0.42 |
| 8:1 | 1.0 | 1.3 | 1.4 | 1.6 | 1.8 | 2.0 | 2.1 | 2.3 | 2.4 | 3.98 ± 0.26 |
| 16:1 | 1.1 | 1.3 | 1.4 | 1.6 | 1.7 | 1.9 | 2.1 | 2.2 | 2.3 | 3.90 ± 0.20 |
| 1:4 | 1.0 | 1.3 | 1.4 | 1.6 | 1.7 | 1.9 | 2.1 | 2.2 | 2.3 | 3.88 ± 0.20 |
| 1:8 | 1.1 | 1.2 | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2.2 | 2.3 | 1.70 ± 0.42 |
| 1:16 | 1.0 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 2.0 | 2.1 | 1.60 ± 0.33 |
| RSD | 1.1 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.9 | 2.1 | 2.2 | 1.64 ± 0.35 |
| ROS | 1.0 | 1.2 | 1.2 | 1.3 | 1.5 | 1.6 | 1.8 | 1.9 | 1.9 | 1.49 ± 0.31 |
| SOIL | 1.0 | 1.3 | 1.4 | 1.5 | 1.6 | 1.8 | 2.0 | 2.1 | 2.1 | 1.64 ± 0.34 |

Note: Samples contain sawdust and oily sludge (SD + OS) in different ratios; RSD; Raw Sawdust. ROS; Raw oily sludge; DAP - Days after planting

## CONCLUSION

Composting of the abundant oily sludge with sawdust as organic amendment provides a cost effective and the most economical sludge disposal method. The low concentration of total petroleum hydrocarbon considered to be a major pollutant in the resultant composts, the levels of the essential elements especially NPK and the slightly acid nature of the final compost is an indication of the safety level of these soil conditioners for plant use. Crude oil sludge can be converted from hazardous waste/pollutant to soil conditioner to enhance improvement in soil fertility towards increased growth and yield of crops to ensure food security.

## ACKNOWLEDGEMENT

The authors gratefully acknowledge the technical assistance by Mr. A. A. Ibuot during this study.

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