REMEDIATION OF HYDROCARBON CONTAMINATED SOIL USING OYSTER MUSHROOM (*Pleurotus ostreatus L.*) AND THE SUBSEQUENT EFFECT ON THE GROWTH AND YIELD OF OKRA (*Abelmoschus esculentus*).IN ABUJA, NIGERIA

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ABSTRACT

The use of oyster mushrooms (Pleurotus ostreatus L) for remediating hydrocarbon-contaminated soil and its impact on the growth and yield of okra (Abelmoschus esculentus) was the focus of the current research. In this study, the goal was to assess the efficiency of bioremediation in soil contaminated with spent engine oil using Oyster Mushrooms (Pleurotus ostreatus L). Soil samples were randomly gathered from the fallow plot within the campus using an auger at a depth of 0–30cm and then combined. A portion of the soil sample underwent routine analysis in the laboratory, while the rest was weighed, placed in the polythene, and transferred to the greenhouse for the study. The soil sample for routine analysis was homogenized, crushed, air-dried, and sieved with a 2mm sieve. The findings via SPSS statisticsl analysis indicated that okra seeds planted in soil treated with oyster mushrooms exhibited improved growth and yield parameters at 8WAP. Soils contaminated with 50ml, 100ml, and 200ml of spent engine oil led to an increase in the total hydrocarbon content in the soil. This study has shown that oyster mushrooms (Pleurotus ostreatus) have the ability to swiftly break down hydrocarbon chains, leading to a rapid reduction of total petroleum hydrocarbons in the substrates. Furthermore, soil biological enhancement methods, such as oyster mushroom inoculation, can enhance the physiological development of okra (Abelmoschus Esculentus (L) Moench) under abiotic stress.

Keywords: Bioremediation, Hydrocarbons, contaminated soils spent engine oil, pollution, oyster mushroom.

INTRODUCTION

Soil pollution due to increasing human activity is one of the major issues faced especially by developing nations. Spent engine oil pollution causes great damage to soil and soil micro-flora. It creates unsatisfactory condition for life in the soil due to poor aeration, immobilization of soil nutrients and lowering of soil pH (Ugoh and Moneke., 2011). It adversely affects fertile land and marine ecosystems and ultimately the health of people around the contaminated site (Kadafa, 2012). These products permeate the soil resulting to changes in the physical and chemical qualities of the soil and thus deterioration of soil characteristics (Semrany *et al*., 2012 and Wapa, et al, 2017). Classified as a carcinogen and neurotic organic pollutant. Information on the impacts of different petroleum contents on microbial communities can provide guidance for the rehabilitation of polluted environments. Thus, it is necessary to understand the responses of microbiomes toward spent engine oil hydrocarbons for the establishment of remediation technologies (Wang *et al*., 2019b).

Bioremediation processes typically involve many different microbes acting in parallel or sequence to complete the degradation process. Bio-stimulation is a bioremediation strategy that has to do with the addition of materials to stimulate the growth of indigenous microorganisms (Kumar and Gopal, 2015). Input of large quantities of carbon sources such as crude oil, lubricating oil, and diesel oil tends to result in rapid depletion of the available pools of inorganic nutrients such as N and P. Hence, the addition of nutrients, either organic or inorganic, will replenish the soil with these nutrients and enhance the activities of indigenous microbes.

Several species of mushrooms have been shown to be effective at degrading oil. The oyster mushroom (*Pleurotus ostreatus*) has been used to break down oil spills and clean up contaminated soil due to its ability to produce enzymes that can break down hydrocarbons (Wu *et al*., 2015). Another mushroom species that has been shown to be effective at degrading oil is the white rot fungus (*Phanerochaete chrysosporium*) (Wu *et al*, 2015). This fungus is able to break down a wide range of organic contaminants, including oil, and has been used in bioremediation efforts to clean up contaminated sites.

Enzymes produced by microorganisms, including fungi, bacteria, and algae, are involved in the breakdown of oil (Liang *et al*., 2017). One type of enzyme that is involved in this process is lipase, which breaks down lipids (fats and oils). Lipases are produced by a wide range of microorganisms and are able to break down hydrocarbons into smaller molecules that can be used as a source of energy. Other enzymes that are involved in the breakdown of oil include proteases, which break down proteins, esterases, which break down esters and cellulases, which break down cellulose (Liang *et al*., 2017).

MATERIALS AND METHODS

Description of the study area

The research was carried out at the University of Abuja's main campus, Faculty of Agriculture Greenhouse, the permanent site of the University of Abuja situated along Abuja-Airport road in Abuja, Nigeria's Capital city. It is located 8°58 north of the equator and 7° 10 easts of the Greenwich meridian. The annual temperature range in the study area is 21-26.7°C and the total annual rainfall I around 1,650mm. Approximately 60% of the yearly rainfall falls during the months of July, August, and September (Itiowe, *et al*., 2019).

Soil sample collection and preparation

Soils was randomly collected at depth of 0–30cm from fallow plot within the campus using an auger and bulked. A portion of the soil sample was transported to the lab for routine analysis while the remaining was weighed, placed in the poly pots and taken to the green house for the research. The soil sample for the routine analysis was homogenized, crushed, air-dried and sieved with a 2mm sieve.

Experimental design and Treatments

The experimental design was the completely randomized design (CRD) and was made up of 3 levels of spent engine oil contamination which includes: 50ml, 100ml and 200ml and 3 levels of oyster mushroom amendment at 20g, 40g and 60g with 3 levels of the combination of spent engine oil and oyster mushroom amendment and a control which was replicated 4 times each.

The treatment combinations are therefore listed as follows:
Control, P1= 50ml of spent engine oil pollution P2= 100ml of spent engine oil pollution P3= 200ml of spent engine oil pollution, O1= 20g of oyster mushroom amendment, O2= 40g of oyster mushroom amendment, O3= 60g of oyster mushroom amendment, P1O1= 50ml of spent engine oil with 20g of oyster mushroom amendment, P1O2= 100ml of spent engine oil with 40g of oyster mushroom amendment, P3O3= 200ml spent engine oil and 60g of oyster mushroom amendment

Data collection on growth and yield parameters

Growth parameters like plant height, number of leaves was taken on germination, flowering, fruiting at intervals. Plant survival was scored using certain growth parameters, including number of days taken for seedling emergence, percentage seedling emergence, percentage plant survival, shoot height, stem width, leaf number, main root length, root and shoot dry weight, number of flowers/plants, as well as yield parameters.

Laboratory analysis

All the soil samples collect before and after treatment were analysed for different propertis followinf discret procedures.

Mushroom spawn production

Spawn was prepared by the method described by Senyah *et al*. (1989). White guinea corn grains were thoroughly washed with tap water and soaked overnight. They were dispensed into spawn bottles and autoclaved at 121°C for 1hour each day for 3 consecutive days. On cooling, the grains were inoculated with four 9mm mycelial discs each bottle, taken from a 14-day-old agar culture of P. *ostreatus* and incubated at 28±20C for 14 days in darkness.

Statistical analysis

The data obtained was subjected to Analysis of variance (ANOVA) and the Least Significant Difference was used to test for significant differences between means at 5% probability levelusing SPSS software.

Results and Discussions

Physical and chemical properties of the soil before treatments

The pre-treated soil's physicochemical properties are presented in Tables 1.

The pH value increased from 6.00 to 6.13, 6.10 to 6.18 and 6.12 to 6.18 respectively for 20g, 40g and 60g of soil treated with oyster mushrooms respectively. Soil treated with 50 ml of spent engine oil slightly decreases the initial soil pH value from 6.13 to 6.11. The soil sample polluted with 100ml of spent engine slightly increased the pH value from 6.11 to 6.14 while the soil treated with 200ml of spent engine oil slightly decreased the soil pH from 6.41 to 6.15. The combined treatment of all the levels of oyster mushroom and all the levels of soil polluted with spent engine oil also increased the pH of the soil from 6.17 to 6.20, 6.13 to 6.17, and 6.15 to 6.19 for the combined treatment of soil treated with 50ml spent engine oil and 20g of oyster mushroom, 100ml of spent engine oil and 40g of oyster mushroom and 200ml of spent engine oil and 60g of oyster mushroom respectively. The pH value of the control soil increased from 5.98 to 6.10 (Table 1).

Table 1: Pre-treatment values of the soil properties under different treatments

Treatments	H_2O pH	% sand	% clay	% silt	% O.C	% O.M	% N	Mg/kg CEC	Mg/kg Av. P
O_1	6.00	70.80	18.20	11.0	0.88	1.52	0.11	9.39	11.60
O_2	6.10	69.80	19.0	11.20	0.85	1.47	0.10	8.70	12.00
O_3	6.12	70.80	19.20	10.0	0.86	1.49	0.11	9.15	11.40
P_1	6.13	69.80	20.0	10.20	0.90	1.56	0.09	8.04	11.80
P_2	6.11	68.64	20.36	11.0	1.01	1.74	0.09	8.71	12.00
P_3	6.41	69.36	18.64	12.0	1.10	1.90	0.10	9.10	12.60
P_1 O1	6.17	69.80	19.20	11.0	1.01	1.74	0.12	9.82	11.90
P_2 O2	6.13	69.36	18.64	12.0	0.63	1.09	0.10	9.26	11.40
P_3 O3	6.15	69.80	19.20	12.0	0.88	1.52	0.09	8.94	11.20
Control	5.98	70.80	18.20	13.0	0.72	1.24	0.09	7.77	11.80

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Organic carbon

The organic carbon value of the soil sample treated with 20g, 40g and 60g of oyster mushroom slightly increased in value from the initial soil organic carbon before the treatments were added. The organic value increased from 0.88 to 1.26%, 0.85 to 2.09% and 0.86 to 0.86% respectively for 20g, 40g and 60g of soil treated with oyster mushrooms respectively. Soil treated with 50 ml of spent engine oil slightly decreases the initial soil organic carbon value from 1.56 to 1.42%. The soil sample polluted with 100ml of spent engine oil slightly increased the organic carbon value from 1.02 to 1.17% while the soil treated with 200ml of spent engine oil slightly decreased the soil organic carbon from 1.10 to 0.90. The combined treatment of all the levels of oyster mushroom and all the levels of soil polluted with spent engine oil also increased the organic carbon of the soil from 1.01 to 1.10%, 0.63 to 0.98%, and 0.88 to 1.18% for the combined treatment of soil treated with 50ml spent engine oil and 20g of oyster mushroom, 100ml of spent engine oil and 40g of oyster mushroom and 200ml of spent engine oil and 60g of oyster mushroom respectively. The organic carbon value of the control soil increased from 0.72 to 0.84%.

Total nitrogen

the nitrogen value of the soil treated with 20g of oyster mushroom slightly increased from 0.11 to 0.13%. the value of the total nitrogen in soil treated with 40g of oyster mushroom was constant with the initial soil nitrogen with a value of 0.10%. On the other hand, the value of total nitrogen in soil treated with 60g of oyster mushroom slightly increased from 0.11 to 0.12%. soil polluted with 50ml and 100ml of spent engine oil slightly increased the total nitrogen from 0.086 to 0.14% and 0.090 to 0.13% respectively. The nitrogen value of soil treated with 200ml of spent engine oil other hand had the same value of 0.10% with the initial value of the soil before treatment. No significant effect of the combined treatments of the oyster and spent engine oil on the soil nitrogen value. The Nitrogen content of the soil before and after the experiment was quite low, below the recommended critical limit of 0.15% (Solulo and Osiname, 1981; Agboola *et al*., 1982) indicating a serious deficiency problem of Nitrogen. This could have been as a result of the absence of Nitrogen fixing bacteria that may have been killed during the heat sterilization process according. However, the increased nitrogen content of soil could be attributed to presence of oyster mushroom which resulted in increased chlorophyll content in leaves and increased photosynthesis, biomass production and accumulation according to the view of Olawuyi *et al*., (2010) and Schippers, (2010) who reported the contribution of oyster mushroom in promoting the vegetative portion of plant, increasing Nitrogen availability, producing large green leaves and necessary for dropping fruits.

Available phosphorus

The available phosphorus value of soil sample treated with 20g, 40g and 60g of oyster mushroom increased in value from the initial available phosphorus before the treatments were added. The available phosphorus value increased from 11.80 to 12.80mg/kg, 11.60 to 13.40mg/kg and 12.00 to 12.70mg/kg respectively for 20g, 40g and 60g of soil treated with oyster mushroom respectively. Soil treated with 50 ml of spent engine oil also increases the initial available phosphorus value from 11.40 to 13.00mg/kg. The soil sample polluted with 100ml of spent engine slightly increase the available value from 11.80 to 12.90mg/kg while the soil treated with 200ml of spent engine oil slightly increased the soil organic matter from 12.00 to 12.20mg/kg. The combined treatment of all the levels of oyster mushroom and all the levels of soil polluted with spent engine oil also increased the soil available phosphorus of the soil from 11.90 to 12.00mg/kg, and 11.40 to 12.92 for the combined treatment of soil treated with 40g of oyster mushroom and 200ml of spent engine oil and 60g of oyster mushroom respectively and a slight decrease was observed in 50ml spent engine oil and 20g of oyster mushroom. The available phosphorus value of the control soil decreased from 11.20 to 10.60mg/kg (Table 2).

Table 2 Post-treatment values of the soil properties under different treatments

Treatments	pH	% sand	% clay	% silt	% O.C	% O.M	% N	CEC	P
01	6.13	68.80	21.0	10.20	1.26	2.18	0.13	10.30	12.0
02	6.18	69.80	20.20	10.00	1.21	2.09	0.10	9.49	13.40
03	6.18	68.64	21.36	10.00	1.30	2.25	0.12	9.85	12.70
P1	6.11	67.80	22.0	10.20	1.42	2.46	0.14	10.62	13.00
P2	6.14	68.80	21.20	10.00	1.17	2.02	0.13	10.34	12.90
P3	6.15	69.80	19.20	11.00	0.90	1.56	0.10	9.43	12.20
P1O1	6.20	70.80	16.20	13.00	1.10	1.90	0.09	9.06	12.00
P2O2	6.17	69.64	18.36	12.00	0.98	1.69	0.09	9.39	12.92
P3O3	6.19	69.80	19.20	11.00	1.18	2.04	0.13	10.29	12.01
Cont.	6.10	68.80	20.20	11.00	0.84	1.45	0.09	8.97	10.60

Cation exchange capacity

A general increase in cation exchange capacity in soils in all the treatment as seen in table 4.2. The soils treated with 20g, 40g and 60g of oyster mushroom had an increase in CEC value from 9.39 to 10.30cmol/kg, 8.70 to 9.49cmol/kg and 9.15 to 9.85cmol/kg respectively. The CEC of the soils polluted with 50ml, 100ml and 200ml of spent engine oil increased from 8.04 to 10.62cmol/kg, 8.71 to 10.34cmol/kg and 9.10 to 9.43cmol/kg respectively. The soil treated with the combined treatment of 50ml of spent engine oil and 20g of oyster mushroom had a reduction in CEC value from 9.82 to 9.06cmol/kg while on the other hand, soils treated the combined treatment of 100ml of spent engine oil and 40g of oyster mushroom, 200ml of spent engine oil and 60g of oyster mushroom had an in increase in CEC value from 9.26 to 9.39cmol/kg and 8.94 to 10.29cmol/kg respectively. The CEC in the control soil increased from 7.77 to 8.97cmol/kg.

Table 3 Growth and yield of okra at 8 Weeks after planting (WAP)

Treatments	CL	LL	LW	NL	NG	NF	CN	NSPP	PDW	PL	LCI	RDW	SDW
Control	36.00^{f}	20.75^{d}	20.00^{g}	10.75^{e}	1.75^{b}	2.00^{a}	2.75^{g}	10.23^{h}	2.03^{b}	5.95^{f}	15.28^{d}	0.67^{b}	1.23^{h}
P1	19.75^{g}	12.00^{e}	11.25^{h}	6.50^{f}	1.25^{c}	0.75^{b}	0.25^{i}	8.42^{f}	0.5^{a}	4.85^{g}	9.35^{g}	0.47^{c}	0.60^{a}
P2	15.25^{h}	8.25^{f}	7.75^{i}	5.00^{h}	1.00^{d}	0.50^{b}	0.50^{h}	7.85^{k}	0.42^{a}	4.74^{g}	9.23^{g}	0.54^{a}	0.58^{a}
P3	15.25^{h}	7.50^{g}	6.75^{k}	5.75^{g}	1.75^{b}	2.00^{a}	0.50^{h}	6.45^{g}	0.37^{a}	3.55^{c}	8.67^{f}	0.38^{d}	0.54^{a}
O1	51.25^{a}	25.50^{b}	23.50^{e}	18.25^{a}	2.00^{a}	2.00^{a}	4.00^{e}	14.27^{e}	2.05^{d}	7.23^{b}	17.68^{h}	0.78^{a}	1.86^{b}
O2	45.00^{c}	26.50^{a}	24.75^{c}	14.50^{c}	2.00^{a}	2.00^{a}	6.00^{b}	10.75^{a}	2.08^{d}	7.46^{b}	18.57^{i}	0.86^{g}	2.26^{c}
O3	43.25^{d}	25.25^{a}	24.50^{d}	11.50^{d}	2.00^{a}	2.00^{a}	5.25^{c}	10.68^{a}	2.57^{g}	8.23^{d}	18.67^{i}	0.75^{a}	2.34^{c}
P1O1	47.00^{b}	25.50^{b}	25.50^{a}	18.75^{a}	2.00^{a}	2.00^{a}	4.75^{d}	9.83^{d}	1.95^{h}	6.85^{a}	16.56^{b}	0.65^{b}	0.79^{d}
P2O2	47.00^{b}	25.75^{ab}	25.00^{b}	16.00^{b}	2.00^{a}	2.00^{a}	6.25^{a}	10.24^{c}	1.88^{j}	6.89^{a}	15.46^{c}	0.72^{a}	0.85^{g}
P3O3	37.75^{e}	22.25^{c}	22.00^{f}	12.50^{bc}	2.00^{a}	2.00^{a}	3.25^{f}	10.05^{c}	1.90^{j}	6.35^{i}	14.98^{k}	0.75^{a}	0.96^{i}

Significant difference was recorded for all treatments at ($P<0.05$) level of significance. The results showed that plant growth parameters performed better in inoculated soil with oyster mushroom than un-inoculated soil irrespective of soil contamination. It was earlier reported that oil inhibits plant growth, reduces germination and subsequent growth, thus resulting in decrease in biomass productivity (Ikhajiagbe and Anoliefo 2012; Ikhajiagbe *et al.,* 2013). There is the possibility that these plants are suffocated as a result of displacement of air from pore spaces by oil, and an increase in demand for oxygen brought about by activities of oil decomposing micro-organisms (De Jong, 2018). This ultimately limits normal diffusion processes. There was a significant reduction in the growth and yield of okra plants in soil polluted with spent engine soil. However, the application of oyster mushrooms (20g, 40g and 60g) significantly enhanced plant growth and yield development in the oil-polluted soil, Reductions in growth and yield of okra occasioned by the presence of oil in soil confirmed earlier reports of Ikhajiagbe (2010). There was a significant increase in crop length and number of leaves in 20g and 40g of oyster-inoculated soil compared to control at 8WAP. Probably, this could be attributed to enhanced nutrient absorption in the root system through oyster mushroom absorptive mechanism. This observation agrees with the findings of some earlier studies by Quinones *et al* 2013 who reported an increase in agronomic growth parameters of okra when oyster mushroom was applied to the soil. The increase in Leaf length in oyster mushroom-treated soil might be a result of increased nutrient uptake. This is supported by the works of George (2012) who noted that oyster mushroom increases phosphorus and micronutrient uptake and growth of their plant host resulting in a significant increase in vegetative growth of the okra plant compared to when there were no oyster mushrooms. There were improved growth and yield parameters of the okra plant in the combined treatment of oyster mushroom and spent engine oil as compared to the growth of the okra plant in soil polluted with spent engine soil alone. This clearly indicates that soil contamination by crude oil can impede the growth and metabolism of okra plants and the oyster mushroom inoculation could have enhanced the biodegradation of various organic chemicals e.g., polycyclic aromatic hydrocarbons (PAHs) present in the crude oil thus releasing the useful mineral nutrients leading to a boost in the growth and metabolism of the growing okra plants. This finding supports the view of Olawuyi *et al*., (2010) who reported the contribution of Nitrogen and Phosphorus sources from oyster mushroom in promoting the vegetative portion of the plant thereby producing large green leaves nitrogen and phosphorus sources from oyster mushroom. The improved yield and growth on okra plant in soil remediated with oyster mushroom could be due to the low carbon content due to hydrocarbon degradation which may have contributed to nutrient source to the plant for the stimulation of growth (Li *et al*., 2020). Improved vegetative yield of plants in crude oil remediated soil using oyster mushroom has been reported by Tanee and Albert (2011), Jonathan *et al*. (2013), Ayolagha and Peter (2013), Okon and Mbong (2013), Benson and Tanee (2016), and Jude and Tanee (2017).

Total Petroleum Hydrocarbon soil under different treatments.

The total petroleum hydrocarbon (TPH) content of the soil before and after the treatments were added is presented in Table 4.

The TPH value for the control sample was reduced from 0.72 to 0.64mg/kg with a percentage reduction of 12.5%. A reduction in TPH content was observed in soil treated with 20g, 40g and 60g of oyster mushroom with a reduction of TPH value from 0.08 to 0.00mg/kg with a reduction value of 100%, 0.56 to 0.04mg/kg with a reduction value of 92.86% and 1.00 to 0.00mg/kg with a reduction value of 100% respectively. On the other hand, an increase in the TPH content was observed in the soil polluted with 50ml, 100ml and 200ml of spent engine oil with an increase in the TPH value from 0.24 to 0.96mg/kg with an increased value of 72%, 0.00 to 0.56mg/kg with an increased value of 56% and 0.00 to 1.00mg/kg with an increased value of 100% respectively(Table 4).

Table 4 Analysis of TPH in the soil

Treatment	Pre-treatments (mg/kg)	Post-treatments (mg/kg)	Percentage reduction (%)
Control	0.72	0.64	12.50
O1	0.08	0.00	100
O2	0.56	0.04	92.86
O3	1.00	0.00	100
P1	0.24	0.96	-72
P2	0.00	0.56	-56
P3	0.00	1.00	-100
P1O1	0.56	0.20	36
P2O2	0.88	0.64	24
P3O3	0.50	0.40	20

P1: 50ml of spent engine oil, P2: 100ml of spent engine oil, P3: 200ml of spent engine oil, O1: 20g of oyster mushroom, O2: 40g of oyster mushroom, O3: 60g of oyster mushroom, P1O1: 50ml of spent engine oil + 20g of oyster mushroom, P2O2: 100ml of spent engine oil and 40g of oyster mushroom, P3O3: 200ml of spent engine oil and 60g of oyster mushroom.

A reduction in the TPH content was also observed in soils treated with the combined treatment of spent engine and oyster mushroom with a reduction from 0.56 to 0.20 with a reduction value of 36%, 0.88 to 0.64mg/kg with a reduction value of 24% and 1.04 to 0.40 with a reduction value 20% for soils treated combinedly with 50ml of spent engine oil and 20g of oyster mushroom, 100ml of spent engine oil and 40g of oyster mushroom and 200ml of spent engine oil and 60g of oyster mushroom respectively (Table 4).

The results of this study indicate that the oyster mushroom can be used to remediate hydrocarbon-contaminated substrates. Table 4 shows that there is a remarkable difference between the Pre-treatments and the post-treatment of soil containing oyster mushrooms, petroleum hydrocarbon (spent engine oil) and its combined treatments. This agrees with the report of Oyedeji *et al.,* (2012) and Chukwumati *et al.,*(2019) which reported that the significant reduction in THC observed in the study after the amendment of the soil with spent mushroom substrate could be due to the degrading action of micro-organisms that utilize hydrocarbon as energy source in their tissues.

Thus, mushrooms have been used to significantly decrease the toxicity of wastes, and degrade mineral contaminants such as arsenic, barium, manganese and many polynuclear aromatic hydrocarbons (PAHs) in contaminants (Stamets, 2013). He also demonstrated that oyster mushroom composts could be used to amend a diesel-contaminated site as they showed a rapid decrease in the total presence of hydrocarbon (TPH) over time. Meanwhile, the result is consistent with studies on *Pleurotus ostreatus* isolated from Spent mushroom compost. Zitte, Awi-Waadu, and John, (2012) showed a significant reduction (85-90%) in TPH content using sawdust inoculated with *Pleurotus ostreatus.* This high level of biodegradation happens because oyster mushroom plays an important role in creating optimal conditions for petrophylic activity (Jørgensen *et al.,* 2010). It can be attributed to the formation of soil aggregates, thereby improving soil aeration, its alkaline pH could also neutralize the acidic nature of the soil. Furthermore, the oyster mushroom also provides the necessary nutrients for bioremediation to take place. The abundant resting hyphae biomass is rich in N and P content and is crucially needed for bioremediation (Hoa *et al.,* 2015). High levels of residual nutrients and enzymes are commonly found in oyster mushrooms (Khammuang and Sarnthima, 2017; Lau *et al.,* 2013). The presence of the Pleurotus Pulmonalis hypha is also crucial, a lignicelulitic fungi that is known to degrade crude oil waste (Da Luz *et al.,* 2015; Salami and Elum, 2010). Its mycelia and lignocellulose substrate function as sorbent for many kinds of organo-pollutants (Chiu *et al.,* 2017). The low hydrocarbon degradation in the control soil (without amendment) confirms the toxicity of crude oil to soil microbial degradation (Ogbo, 2019). Crude oil blocks the air pores (Essien and John, 2015) and water pores of soil (hydrophobic). This reduces water holding capacity and aeration in the soil (Abosede, 2013) depriving the soil of oxygen and water; thus, affecting the soil-water and soil-air relations for efficient hydrocarbon degradation.

Conclusion

The results of the study showed the improvement of soil properties in soil treated with oyster mushrooms and an improved soil property was also observed in the soil treated with combined treatment of oyster mushrooms and spent engine oil. The growth and yield parameters were highest in soil remediated with oyster mushrooms. Low yield and growth of okra plant was observed in soil polluted with spent engine oil while on the other hand, higher yields and growth of okra plant was recorded in soil treated with 20g, 40g and 60g of oyster mushroom. The physiological development of Okra (*Abelmoschus Esculentus* (L) Moench) under abiotic stress could be improved through soil biological improvement strategies such as oyster mushroom inoculation. Oyster mushrooms could ameliorate unfavourable conditions posed by crude oil contamination by enhanced production of oxidative enzymes and overall improvement in soil aggregation.

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