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Uptake and Distribution of Total Petroleum Hydrocarbon by Sunflower from Crude Oil Contaminated Soils Using Agro-Industrial Wastes as Soil Amendments

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Abstract

This study investigated the growth performance of sunflower (*Helianthus annuus* L.) under different concentrations of petroleum hydrocarbon contaminated soils. This was with a view to assessing the remediating potentials of the test crop when different rates of agro-industrial wastes were used as soil amendments. The experiment was conducted in the greenhouse of the Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife. It was a 5 x 3 x 3 factorial complete randomized design, consisting of 135 polythene pots, each containing five kg of sandy topsoil. Poultry waste and ashed sawdust in different ratios [0:100; 25:75; 50:50; 75:25 and 100:0] gave five manure mixtures which were applied at three levels (0, 4 and 8 t ha^{-1}) as soil amendments. These manures significantly ($p < 0.05$) increased the uptake and accumulation of total petroleum hydrocarbon in the root (0.19-0.46 mg kg^{-1}), shoot (0.75-1.71 mg kg^{-1}) and grains (0.13-0.26 mg kg^{-1}) of sunflower; however, with superior influence from 8 t ha^{-1} containing higher poultry waste and at 1% crude oil soil contamination. The study concluded that sunflower has potential for the cleaning-up of petroleum hydrocarbon from crude oil contaminated soil, particularly when high composted poultry waste proportion in the manure mixtures was used as soil enhancer in the humid tropical climate.

Keywords:
Ashed sawdust, composted poultry waste, contaminated soil, petroleum hydrocarbon uptake, sunflower.

Introduction

Before the discovery of crude oil in Nigeria, the country's economy survived and flourished majorly on agriculture (Ekundayo and Obuekwe, 1997). In 1956 however, Shell British Petroleum (now Royal Dutch Shell) discovered crude oil at Oloibiri, a village in the Niger Delta region and commercial production began in 1958 (Njoku *et al.*, 2000). Till date, most of the oil wells in Nigeria are found in the Niger Delta. Crude oil exploitation has had certain impacts on the Nigeria economy both positively and adversely. For the past three decades, crude oil has been a major source of revenue, energy and foreign exchange for the Nigerian economy (Odularu, 2007). Odularu (2007) further indentified soil contamination from crude oil as one major problem of environmental degradation as many of the surrounding communities within which the oil wells are exploited suffer serious soil and water pollution. The traditional livelihoods of the people living in this region are continually being destroyed (Ayotamuno *et al.,* 2006).

Crude oil, a complex mixture of hydrocarbon, liquid in its natural state is classified into aliphatic, alicyclic and aromatic compounds (Atlas and Bartha, 1973), including heavy metals (Osam *et al*., 2011). Most of these constituents are known to be toxic at different levels to different living organisms. This has raised considerable concern on crude oil pollution especially of the soil and water ecosystems. Changes in soil properties due to contamination with crude oil and its derivatives can lead to water and oxygen deficit as well as shortage to available forms of nitrogen and phosphorous (Andrade *et al*., 2004). Contamination of the soil environment can limit protective functions; upset metabolic activity, unfavorably affects its function and chemical characteristics, reduced soil fertility and negatively influence plant production (Smith *et al.*, 2006).

Also, crude oil pollution causes low permeability and low infiltration of water into the soil (Andrade *et al*., 2004). These conditions can lead to accumulation of water on the soil surface and an artificial drought in the subsurface layer of soil, which could lead to difficulty for the roots to absorb water and nutrients (Smith *et al.*, 2006). As a result of associated problems to crude oil polluted sites, many of the sites are being abandoned due to their inability to support agricultural activities. Of all the remediation methods, phytoremediation technology is more favorable due to its potential for cleaning up environment and the overall aesthetic perfection of the contaminated sites (Fayiaga *et al*., 2004). High biomass producing plant species such as sunflower have potential for extracting heavy metals in polluted soils, especially in the presence of EDTA (Yanshan *et al*., 2004), arbuscular mycorrhiza (Awotoye *et al*., 2009) and organic fertilizers (Adewole *et al*., 2010). However, there is a dearth of information on the use of sunflower for the remediation of crude oil contaminated soil when manures from poultry and sawdust wastes are used as soil enhancers. The abundance of these wastes in major cities of Nigeria and the way they are incessantly burnt is not environment-friendly.

This study therefore assessed the ability of sunflower (*Helianthus annuus* L.) to remediate crude oil contaminated soil when different rates of agro-industrial wastes (composted poultry manure and ashed sawdust) were used as soil amendments. The study also determined the pattern of distribution of total hydrocarbon in different parts of sunflower when cultivated in crude oil contaminated soils.

Materials and Methods

Experimental design and agronomic details

The experiment was conducted in the greenhouse of the Faculty of Agriculture, Obafemi Awolowo University (OAU), Ile-Ife, Nigeria. Bulk surface soil samples (0–15 cm) were collected from exhaustively cropped farm in the University, air-dried for seven days, sieved using 2 mm sieve to remove the debris and stones. The sieved soil samples were analyzed using standard methods to know their properties. Fresh poultry droppings were collected from the OAU Teaching and Research Farm, Ile-Ife, heaped under a shed and composted aerobically for three months. Sawdust was collected from a sawmill, also in Ile-Ife and ashed. The composted poultry waste (Pw) and ashed sawdust (Sd) were mixed at different ratios [0:100, Pw_0Sd_{100}; 25:75, $Pw_{25}Sd_{75}$; 50:50, $Pw_{50}Sd_{50}$; 75:25, $Pw_{75}Sd_{25}$ and 100:0, $Pw_{100}Sd_0$] to give five agro-industrial wastes as manure treatments. The crude oil obtained from Nigerian National Petroleum Corporation, Eleme, Rivers State was prepared to different levels of concentrations [0, 1 and

2% (v/v)] as contaminants.

A total of 135 polythene pots having drainage holes at the bottom, each with five kilogram of air-dried and sieved surface soil were placed on the tables in the greenhouse and doses of crude oil contaminants and manure mixtures were applied. This was a factorial combination of three levels of contaminants; each was replicated thrice with five agro-industrial wastes as manure treatments at three levels (0, 4 and 8 t ha^{-1}) of application in a completely randomized design. The crude oil contaminants and manure mixtures were applied to degraded surface soil, moistened with deionised water to field moisture capacity and thereafter allowed to equilibrate for two weeks.

Viable seeds of sunflower were planted into each pot at four seeds per pot and thinned to two stands per pot two weeks after sowing. The thinned stands were retained in their respective pots. The pots were maintained weed-free and regularly watered throughout the experimental period, but with caution to prevent leaching. At 16 weeks after sowing when the full physiological maturity was attained, the seeded heads were cut off from the stems, sun-dried for five days to reduce the moisture content, hand-threshed, weighed and stored.

Laboratory analyses

The sunflower plants were carefully extracted from the polythene pots by allowing the running tap water to flush out the attached soil particles. The extracted plants were thereafter rinsed with deionised water. A clean kitchen knife was used to separate the sunflower plants into roots and shoots, oven-dried for 48 h at 70 °C, weighed, ground, and stored. The pre- and post-soil tests were carried out to assess the selected properties and petroleum hydrocarbon contents of the soil. The particle size analysis was determined using hydrometer method in 5% Calgon as dispersing agent as outlined in Odu *et al*., (1986). Soil pH was determined potentiometrically in 1:1 soil-water ratio (McLean, 1982). Organic carbon content of the soil and manure wastes was determined using Walkey-Black method (Nelson and Sommers, 1982). Total nitrogen of the soil and manure wastes was determined by the macro-Kjeldahl method (Bremner and Mulvaney, 1982). The available phosphorus of the soil and manure wastes was determined by Bray P_1 method (Olsen and Sommers, 1982). Calcium and magnesium ions in the soil and manure wastes were extracted using 1 M ammonium acetate buffered at pH 7.0 (Thomas, 1982) and their concentrations in the extracts were measured using Buck Scientific 210/211 VGP (East Norwalk, Connecticut, USA) Atomic Absorption Spectrophotometer. Total petroleum hydrocarbon in the soil, root, shoot and grain samples of sunflower were extracted using 20 ml of xylene as the extracting solvent on 10 g of each of the samples (Greenberg, 1981). The concentrations were later read on the calibrated spectrophotometer at 650 nm wavelenght. The mean concentrations were thereafter multiplied by mean dry weight to obtain the uptake of different parameters in parts of the test plant.

Statistical analysis

The data obtained were subjected to descriptive statistics and analyses of variance to test for their treatment effect. Test of significance for differences in means was statistically compared using Duncan's multiple range tests at $p < 0.05$.

Results and Discussion

The results of analyses of agro-industrial wastes used as manures and crude oil for the study are presented in Table 1. Exceedingly high Carbon/Nitrogen (C/N) ratio (220.4) of sawdust may encourage the organic carbon of this manure to remain for a longer period as additions to native carbon pool of the soil. The characteristics of the soil for this study are presented in Table 2.

Table 1: Selected Properties of Agro-industrial Wastes and Crude Oil Used

Property	Sawdust	Poultry compost	Crude oil
Organic Carbon (g kg^{-1})	198.4	33.4	-
Total N (g kg^{-1})	0.9	4.7	-
Available P (mg kg^{-1})	3.9	4.9	-
Potassium (cmol kg^{-1})	6.8	21.6	-
Magnesium (cmol kg^{-1})	4.5	13.9	-
Calcium (cmol kg^{-1})	64.5	33.8	-
Carbon/Nitrogen Ratio	220.4	7.1	-
Total petroleum hydrocarbon (mg L^{-1})	-	-	155.9

Table 2: Selected Properties of Soil used for the Experiment

Soil property	Value
Soil pH (1:1 soil-water)	6.60
Total Nitrogen (g kg^{-1})	0.12
Available Phosphorus (mg kg^{-1})	10.65
Potassium (cmol kg^{-1})	0.47
Magnesium (cmol kg^{-1})	0.12
Calcium (cmol kg^{-1})	0.48
Organic Carbon (g kg^{-1})	9.30
Carbon/Nitrogen Ratio	77.50
Total Petroleum Hydrocarbon (mg L^{-1})	0.12
Textural Class	Sandy

The soil had a pH of 6.60 in 1:1 soil-water medium, indicating a slightly acidic condition. The proportions of sand, silt and clay of the soil were: 860.0, 84.0 and 56.0 g kg^{-1} respectively, indicating a sandy soil texture and typical of a degraded tropical soil (Adeoye *et al*., 2005). The mean dry weight of root, shoot and grains of sunflower as influenced by different rates of agro-industrial manures in crude oil contaminated soils are presented in Table 3. Soil toxicity caused by crude oil at 2% crude oil contamination could have had adverse effect on the seed embryo and hence prevented sunflower seeds from sprouting.

Poultry manures positively enhanced the survival and growth rates of sunflower seedlings. Similar results were observed by Nwaichi *et al.* (2010) when poultry manures and urea fertilizers were used as soil amendments for the phytoextraction of heavy metals in crude oil contaminated soils using *Mucuna pruriens* and *Sphenostylis stenocarpa* as the test plants. Generally, addition of agro-industrial manures significantly ($p < 0.05$) increased the dry weight of root, shoot and grains of sunflower. However, increase in crude oil contamination levels significantly ($p < 0.05$) reduced the dry weight of root, shoot and grains of sunflower. Agbogidi *et al.* (2007) obtained similar results of reduced biomass yield of maize cultivated on crude oil contaminated soil and attributed this to limited diffusion processes of reduced essential plant nutrients. However, highest mean values of root and shoot dry biomass and grains of sunflower were obtained with poultry manure only ($Pw_{100}Sd_0$) applications, irrespective of contamination levels.

The low C/N ratio in manure mixtures $Pw_{100}Sd_0$ and $Pw_{75}Sd_{25}$, might have contributed significantly to increased dry weight of root, shoot and grains of sunflower. The high N and P nutrients released as a result of low C/N ratio could have enhanced the overall growth performance of the test crop. This superiority in the nutrients release of $Pw_{100}Sd_0$ and $Pw_{75}Sd_{25}$ manure mixtures agreed with the findings of Olayinka (2009) when poultry manure with maize straw/sawdust, singly and in combination were compared to grow tomato. Nutrients mineralization for plant up, particularly N when the C/N ratio of the organic material is 20 or less was recommended by Olayinka (2009). The overall sequence of $Pw_{100}Sd_0 = Pw_{75}Sd_{25} > Pw_{50}Sd_{50} > Pw_{25}Sd_{75} > Pw_0Sd_{100}$ manure treatments on the mean dry weights of root, shoot and grains was obtained. High lignin content in sawdust alone and its mixtures would have delayed their decomposition rates; hence, the rate of nutrients release will be slow.

Table 3: Effects of Agro-industrial Manures on the Mean Dry Weights (g Pot^{-1}) Of Root, Shoot and Grains of Sunflower Cultivated in Crude Oil Contaminated Soils

Treatment	Root	Shoot	Grain	Root	Shoot	Grain	Root	Shoot	Grain
		0%			1%				2%
CT	0.59^{ns}	16.8^{b}	0.53^{b}	0.43^{ns}	12.5^{b}	0.30^{b}	*	*	*
				4 t ha^{-1}					
Pw_0 Sd_{100}	0.55^{ns}	15.7^{b}	0.66^{b}	0.43^{ns}	12.4^{b}	0.39^{b}	*	*	*
Pw_{25} Sd_{75}	0.67^{ns}	19.0^{b}	0.80^{b}	0.61^{ns}	17.3^{a}	0.55^{b}	*	*	*
Pw_{50} Sd_{50}	0.57^{ns}	16.4^{b}	0.68^{b}	0.48^{ns}	13.6^{b}	0.43^{b}	*	*	*
Pw_{75} Sd_{25}	0.73^{ns}	21.8^{a}	0.88^{b}	0.58^{ns}	16.7^{a}	0.52^{b}	0.38^{ns}	10.8^{ns}	0.27^{ns}
Pw_{100} Sd_0	0.75^{ns}	21.3^{a}	0.90^{b}	0.58^{ns}	16.5^{a}	0.52^{b}	0.44^{ns}	12.5^{ns}	0.22^{ns}
				8 t ha^{-1}					
Pw_0 Sd_{100}	0.63^{ns}	18.1^{b}	0.82^{b}	0.41^{ns}	11.8^{b}	0.37^{b}	*	*	*
Pw_{25} Sd_{75}	0.67^{ns}	19.2^{b}	0.87^{b}	0.45^{ns}	12.9^{b}	0.41^{b}	*	*	*
Pw_{50} Sd_{50}	0.68^{ns}	19.4^{b}	0.88^{b}	0.56^{ns}	16.1^{a}	0.50^{b}	*	*	*
Pw_{75} Sd_{25}	0.74^{ns}	21.2^{a}	0.96^{b}	0.59^{ns}	16.8^{a}	0.52^{b}	0.47^{ns}	13.3^{ns}	0.38^{ns}
Pw_{100} Sd_0	0.81^{ns}	23.0^{a}	1.60^{a}	0.61^{ns}	17.5^{a}	1.05^{a}	0.51^{ns}	15.0^{ns}	0.52^{ns}

Means followed by the same letter(s) within a column are not significantly different at $p < 0.05$ by Duncan Multiple Range Test.

Legend: *CT= Control (Zero organic manure application), Pw_0 Sd_{100} = 0% Poultry waste and 100% Sawdust, Pw_{25} Sd_{75} = 25% Poultry waste and 75% Sawdust, Pw_{50} Sd_{50} = 50% Poultry waste and 50% Sawdust, Pw_{75} Sd_{25} = 75% Poultry waste and 25% Sawdust, $Pw_{100}Sd_0$ = 100% Poultry waste and 0% Sawdust and * = No plant for analysis*

Effects of agro-industrial manures on the distribution pattern of total petroleum hydrocarbon uptake in the root, shoot and grains of sunflower cultivated in crude oil contaminated soils are presented in Table 4. Higher uptake of TPH was obtained in different parts of sunflower with increase in the proportions of poultry manure in the manure mixtures applied. The overall sequence of TPH uptake was comparable with mean weight biomass earlier given. The enhanced biomass of sunflower produced when high poultry waste proportion was in the manure mixtures also influenced TPH uptake. Lowest TPH uptake was obtained with 100% sawdust application as soil amendment. Sawdust alone and sawdust with lower proportion of poultry waste as soil amendments may probably require longer period of time to decompose and mineralize for the test crop to use. This may be the reason why highly lignified or raw sawdust was not recommended by Ahmed (2013) as soil amendment because the growth performance and biomass production of crops could be adversely affected. Higher TPH were taken up and stored by sunflower in 1% crude oil soil contamination than in 2%. Low uptake of TPH at 2% may not be unconnected with poor biomass yield and low growth performance of sunflower plant at high crude oil soil contamination.

Table 4: Effects of Agro-industrial Manures on the Distribution Pattern of Total Petroleum Hydrocarbon Uptake (mg Kg^{-1}) in the Root, Shoot and Grains of Sunflower Cultivated in Crude Oil Contaminated Soils

Treatment	Root	Shoot	Grain	Root	Shoot	Grain	Root	Shoot	Grain
		0%			1%				2%
CT	0.01^{ns}	0.01^{ns}	0.01^{ns}	0.03^{b}	0.37^{b}	0.06^{b}	*	*	*
				4 t ha^{-1}					
Pw_0 Sd_{100}	0.01^{ns}	0.01^{ns}	0.01^{ns}	0.19^{a}	0.75^{b}	0.13^{a}	*	*	*
Pw_{25} Sd_{75}	0.02^{ns}	0.01^{ns}	0.01^{ns}	0.23^{a}	1.07^{a}	0.15^{a}	*	*	*
Pw_{50} Sd_{50}	0.02^{ns}	0.02^{ns}	0.02^{ns}	0.29^{a}	1.01^{a}	0.18^{a}	*	*	*
Pw_{75} Sd_{25}	0.02^{ns}	0.02^{ns}	0.02^{ns}	0.28^{a}	1.09^{a}	0.19^{a}	0.22^{ns}	0.78^{ns}	0.10^{ns}
Pw_{100} Sd_0	0.02^{ns}	0.03^{ns}	0.02^{ns}	0.31^{a}	1.07^{a}	0.18^{a}	0.25^{ns}	0.95^{ns}	0.11^{ns}
				8 t ha^{-1}					
Pw_0 Sd_{100}	0.01^{ns}	0.02^{ns}	0.02^{ns}	0.27^{a}	1.10^{a}	0.17^{a}	*	*	*
Pw_{25} Sd_{75}	0.02^{ns}	0.03^{ns}	0.03^{ns}	0.33^{a}	1.20^{a}	0.19^{a}	*	*	*
Pw_{50} Sd_{50}	0.02^{ns}	0.03^{ns}	0.03^{ns}	0.40^{a}	1.51^{a}	0.23^{a}	*	*	*
Pw_{75} Sd_{25}	0.02^{ns}	0.03^{ns}	0.03^{ns}	0.44^{a}	1.71^{a}	0.23^{a}	0.41^{ns}	1.73^{ns}	0.19^{ns}
Pw_{100} Sd_0	0.02^{ns}	0.04^{ns}	0.04^{ns}	0.46^{a}	1.66^{a}	0.26^{a}	0.54^{ns}	1.68^{ns}	0.23^{ns}

Means followed by the same letter(s) within a column are not significantly different at $p < 0.05$ by Duncan Multiple Range Test.

Legend: *CT= Control (Zero organic manure application), Pw_0 Sd_{100} = 0% Poultry waste and 100% Sawdust, Pw_{25} Sd_{75} = 25% Poultry waste and 75% Sawdust, Pw_{50} Sd_{50} = 50% Poultry waste and 50% Sawdust, Pw_{75} Sd_{25} = 75% Poultry waste and 25% Sawdust, $Pw_{100}Sd_0$ = 100% Poultry waste and 0% Sawdust and * = No plant for analysis*

Conclusion

Composted poultry wastes and ashed sawdust as manure mixtures enhanced the biomass production of sunflower in crude oil contaminated soils. Highest uptake and accumulation of petroleum hydrocarbon was obtained in the shoot of the test crop. However, superior influence from 8 t ha^{-1} of $Pw_{100}Sd_0$ and $Pw_{75}Sd_{25}$ manure applications at 1% crude oil soil contamination was obtained. This, by implication suggested that the remediation of petroleum hydrocarbon using sunflower plant from crude oil soil contamination at lower concentration when high composted poultry waste proportion in the manure mixtures (poultry waste + ashed sawdust) was used as soil enhancer is feasible. Such mixture manures when properly used can help reclaim the abandoned crude oil contaminated humid tropical soils.

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