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Effects of different levels of spent engine oil on soil physicochemical properties using different texturally contrasting soils

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ABSTRACT: The relation between soil type and different levels of spent engine oil pollution on soil physicochemical properties was studied. Sandy loam (SL), Loamy sand (LS), and Sandy clay loam (SCL) were potted with a polythene bag and polluted with 10% w/w (122 mL/kg), 20% w/w (245 mL/kg) and 0% w/w (0 mL/kg) of spent engine oil. The soil was thoroughly mixed with spent engine oil and allowed to stay for three weeks to allow for proper absorption of the engine oil. Air-dried crushed and sieved poultry manure was applied to each polythene bag at 40 t/ha. The spent engine oil-organic manure mixture was watered to field capacity 3 times per week for two weeks, sunflower seeds were sown. The study lasted for 12 weeks, soil samples were collected and analyzed**.** Spent engine oil increases the bulk density, aggregate stability, state of aggregation, mean weight diameter, phosphorus, Nitrogen, Organic matter, and pH both in water and KCl, it decreases the cation exchange capacity, hydraulic conductivity, total porosity, and microporosity. The effect of spent engine oil on soil physicochemical properties depends on soil type and pollution level. Overall, the results show that the loam sand soil can still withstand the growth of sunflower plants at a 10% pollution rate.

Keywords: Physicochemical properties, pollution, soil type, spent engine oil, sunflower.

INTRODUCTION

The specific definition of soil quality for a particular soil is dependent on its inherent capabilities, intended land use, management goals, and their interactions. For instance, optimum levels of organic matter (and other soil properties) will differ depending on the condition under which the soils are formed, leading to variation in potential functioning (Salma, 2011). Soil physical and chemical indicators are of paramount importance in soil quality assessment. Physical indicators are related to the arrangement of solid particles and pores. Examples include topsoil depth, bulk density, porosity, aggregate stability, texture, crusting, and compaction. Physical indicators primarily reflect limitations to root growth, seedling emergence, infiltration, or water movement within the soil profile, indicate how well water and chemicals are retained and transported, and estimate soil erosion and variability. They also indicate productivity potential, even the out landscape, and geographic variability, and describe the potential for leaching, and erosion. Chemical indicators include measurements of pH, salinity, organic matter, phosphorus concentrations, cation-exchange capacity, nutrient cycling, and concentrations of elements that may be potential contaminants (heavy metals, radioactive compounds, etc.) or those that are needed for plant growth and development. The soil chemical condition affects soil-plant relations, water quality, buffering capacities, availability of nutrients and water to plants and other organisms, mobility of contaminants, and some physical conditions, such as the tendency for a crust to form (Salma, 2011). The degree of acidity and alkalinity of soil is an important property affecting many other physicochemical and biological properties which can also be used as an index to assess soil quality (Ikuesan *et al*., 2019).

Severe hydrocarbon contamination implies low agricultural productivity and reduced source of livelihood in the affected area (Ikuesan *et al*., 2019). Appreciable increases in organic matter contents follow the pollution of sandy loam soil against the control soils followed by a remarkable gradual decrease in the percentage of organic matter with time which might have resulted from crude oil mineralization by the native microbial population (Oyem and Oyem, 2013). This increased organic carbon will create nutritional imbalance, especially in carbon and nitrogen since crude oil contains many carbon-containing compounds. Muhammad *et al*., (2016) showed that motor oil treatment had no significant effect on the soil texture. Crude oil contamination can potentially alkalinize marsh soils, adversely affect soil fertility and physical properties, and cause deterioration of marshes (Wang *et al*., 2013). According to Uquetan *et al*., (2017), soils with a lower concentration of spent engine oil have reduced redox potential. Ewetola (2013) noted that crude oil pollution had no significant influence on sand particles. The concentrations of total petroleum hydrocarbon in crude oil significantly affected soil temperature but soil temperature also significantly fluctuated with seasons (Wang, *et al*., 2013). As cited in Luhach and Chaudhry (2012), the toxicity effect noticed in contaminated soils might not be limited to the contaminant concentration but also due to soil type and properties, hydrocarbon type, microbial community composition, and plant species. The level of contamination determines the extent of damage and inhibition. Also, the lethal concentrations of petroleum contaminants in different plants vary.

The paper studies the relationship between soil type and levels of spent engine oil pollution on soil physicochemical properties. Research has been carried out on the effects of spent crude oil on the physicochemical properties of soil, but this paper assessed spent crude oil in the presence of different soil types. Since different soils have different sand, silt, and clay percentages, their interaction with spent crude oil should be considered.

MATERIALS AND METHODS

Study area and soil sampling

The study was conducted in a greenhouse belonging to the Department of Soil Science University of Nigeria Nsukka located within the derived savanna zone in the eastern part of Nigeria by latitude 6°54N and longitude 7°24E with an altitude of 447.26 m above sea level (Oko-Ibom and Asiegbu, 2006). The area is characterized by a humid tropical climate with wet (April- October) and dry (November-March) seasons, and a mean annual rainfall of 1750 mm bimodally distributed with peaks in July and September; mean annual maximum (day) and minimum (night) temperatures of 31°C and 21°C respectively (UNN Meteorological Station, 2010). Relative humidity ranges between 70 to 80% (Oko-Ibom and Asiegbu, 2006), it falls below 60% during the period of Harmattan- a short period of about three weeks of hazy and dry weather usually from December through January (Asadu *et al*., 2001).

Three soils of different textural classes were collected from Ekwegbe Nsukka and the University of Nigeria Teaching and Research Farm Nsukka. Two soils were obtained from Ekwegbe, Nsukka while one was collected from the University of Nigeria Teaching and Research Farm. The three different soils were taken to the laboratory for mechanical analysis (Bouyoucous, 1986) to determine their textural classes (Table I).

Experimental setup

The study involves two factors. The factors are soils of different textures and three levels of crude oil pollution. The soils used for the study were air-dried, crushed, and passed through a 2 mm sieve and 4 kg of the soils were weighed into twenty-seven perforated polythene bags. The soil samples were subjected to three levels of spent engine oil pollution- 122 mL/kg (10% w/w), 245 mL/kg (20% w/w), and 0 mL/kg serving as control. The soil samples were thoroughly mixed with spent engine oil and allowed to stay for three weeks to allow for proper absorption of engine oil. Air-dried, crushed, and sieved poultry manure was applied to each polythene bag at 40 t/ha. The soil-spent engine oil-organic manure mixture was watered to field capacity 3 times per week for two weeks after which the sunflower was sown. Sunflower seeds were sown into 27 perforated polythene bags each at the rate of three seeds per bag, but the seedlings were thinned down to one plant per bag two weeks after planting. The experiment was arranged in a 3x3 factorial with three replications giving twenty-seven experimental units. The plants were watered to field capacity thrice a week and allowed to grow freely in the greenhouse for three (3) months.

Sampling technique

From each polythene bag, undisturbed soil core samples, each 5.5 cm (diameter) and 5.0 cm (length) were collected from the topsoil (0-20 cm) and used for hydraulic conductivity, bulk density, and total porosity determination. Also, disturbed soil samples were collected from each polythene bag using a knife at a depth of 0-20 cm, air-dried and sieved through 4.76 mm and 2.0 mm sieve, and soil aggregates that passed through the 4.76 mm sieve, but

Table I. Particle size distribution of the soils before any pollution.

Soils	Coarse sand (%)	Fine sand (%)	Total sand (%)	Silt (%)	Clay (%)	Textural class
1	26.76	59.64	86.40	3.30	10.30	Loamy sand
2	18.10	45.90	64.00	14.00	22.00	Sandy clay loam
3	11.90	44.50	56.40	33.30	10.30	Sandy loam

were retained on the 2 mm sieve was kept for aggregate stability analysis, soil that passed through 2 mm were kept for determination of chemical properties (organic carbon, pH, CEC, N, P).

Soil analysis

The particle size analysis was done by the Bouyoucuous hydrometer method as described by Gee and Or, (2002). Sodium hydroxide (NaOH) was used as the dispersal agent instead of sodium hexametaphosphate (Calgon). Saturated hydraulic conductivity (Ks) was determined by the constant head permeameter method (Klute and Dirksen, 1986) using Henri Darcy's equation as described by Youngs (2001)

$K = (Q * \Delta Z) / (AT\Delta H * 60)\ (cm^3 / hr)$ 1

Where Q = Steady-state volume of flow (cm^3), ΔZ = Length of core (cm), A = Cross-sectional area (cm^2), T= Time interval (h), ΔH = Hydraulic head (cm)

Bulk density was determined by the core method (Blake and Hartage, 1986).

Total porosity (Tp) was estimated from bulk density value assuming a particle density of 2.65 g/cm as thus:

$Tp = (1 - Bd/Pd) * 100$ 2

Where Tp= total porosity, Bd= bulk density, Pd= particle density

Macro porosity was estimated from the saturated and tension weight thus:

Macro porosity= (Saturated weight – Tension weight)/Volume of core 3

Microporosity was determined from total porosity and macro porosity.

Total porosity= macro porosity + microporosity 4

The aggregate distribution in the soil was determined by the wet sieving technique described by Kemper and Rosenau (1986). In this procedure, 25 g of less than 4.76 mm air-dried aggregates were placed on the topmost of a nest of four sieves of diameters 2, 1, 0.5, and 0.25 mm. The samples were presoaked in water for 5 mins before oscillating vertically in water 30 times (along four amplitude). The resistant aggregates on each sieve were dried at 105□C for 24 h and weighed. The mass of less than 0.25 mm fraction was obtained by differences between the initial sample weight and the sum of the weight collected on the 2, 1, 0.5, and 0.25 mm. The per cent water-stable aggregates (WSA) on each sieve were determined thus:

$WSA = (Mwsa - Ms) / (Mt - Ms) * 100$ 5

Where Mwsa = mass of the aggregates plus sand(g), Ms = mass of the sand fraction alone (g), Mt = mass of the sieved soil (g)

The method of Van Bavel (1950), modified by Kemper and Rosenau (1986) was used to evaluate the mean-weight diameter of aggregate as thus:

$MWD = {}^{X1}\ {}_{W1} in \sum = 1$.................. 6

Where MWD = mean- weight diameter of aggregate (mm), x1 = mean diameter of the aggregates, w1= proportion of the total sample weight in the corresponding size

Soil pH was determined in 1:2:5 soil water ratios using a digital pH meter, Soil organic carbon (SOC) was determined by the modified Walkey and Black wet digestion and oxidation method (Nelson and Sommers, 1996). Total nitrogen was determined by the micro-Kjeldahl digestion and distillation method as described by Bremmer (1996). Available phosphorus was extracted using the Bray-II method described by Bray and Kurtz (1945), and available phosphorus in the extract was determined using the molybdate blue colour method. Cation exchange capacity was determined using the ammonium acetate method displacement method.

Statistical analysis

Data generated after the experiment was subjected to analysis of variance (ANOVA) using GenStat Discovery Software, Edition 4. Differences in means were deemed

Table II. The main effect of spent engine oil on the physical properties of the soil.

Ps (%)	Ks (cmhr^{-1})	BD (gcm^{-3})	TP (%)	Macp (%)	Micp (%)	AS (%)	SA (%)	MWD (mm)
P0	13.10	1.39	47.68	3.81	43.85	45.22	40.50	1.12
P10	4.70	1.61	40.24	3.69	35.71	82.36	75.70	2.43
P20	4.60	1.60	39.58	4.37	35.21	90.37	76.00	2.74
F-LSD$_{0.05}$	5.39	0.06	2.40	N. S	2.74	4.38	5.05	0.13

Note: Ks = saturated hydraulic conductivity, BD=bulk density, TP= total porosity, AS = aggregate stability, SA = state of aggregation, Macp = macro porosity, Micp = microporosity, MWD = mean weight diameter, p0 = 0% pollution, p10 =10% pollution, p20 = 20% pollution.

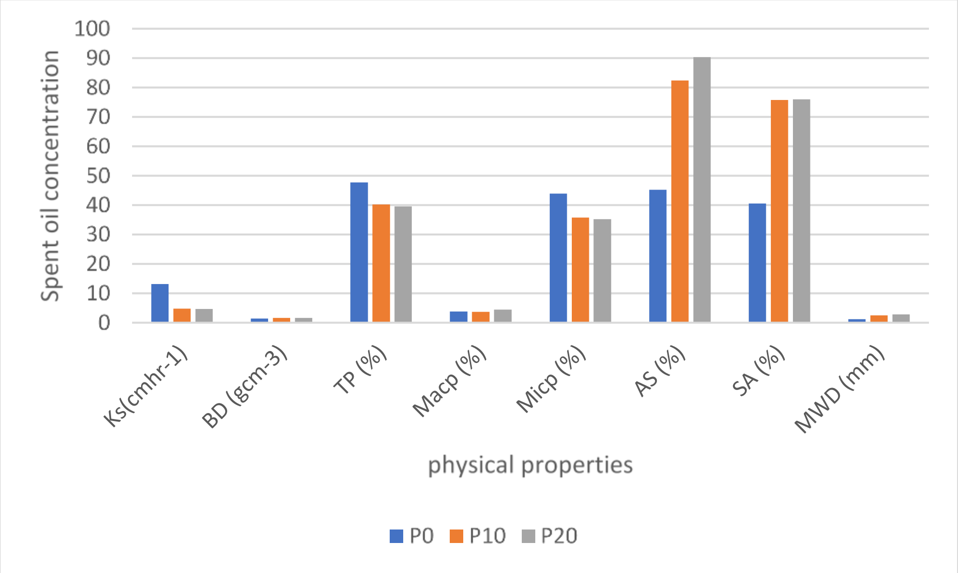

Figure I. The main effect of spent engine oil on the physical properties of the soil.

significant at a 5% probability level. The mean was separated using the least significant differences (LSD) at a 5% probability level Obi (2002).

RESULTS

Physical and chemical properties

There was an increase in the bulk density, aggregate stability, state of aggregation, mean weight diameter, and a decrease in hydraulic conductivity, total porosity, and microporosity across the different pollutants (Table II, Figure I). Macro porosity was non-significant ($p<0.05$). For bulk density, aggregate stability, state of aggregation and mean weight diameter 0% pollution has the lowest value (1.39 gcm^{-3}, 45.22%, 40.50%, and 1.12 mm respectively, $p<0.05$), then there was an increase at 10% pollution (1.61 gcm^{-3}, 82.36%, 75.70% and 2.43 mm respectively) at 20% pollution the bulk density of the soil decreased slightly to 1.60 gcm^{-3} while the aggregate stability, state of aggregation, and mean weigh diameter further increased to (90.37%, 76.00%, and 2.74 mm respectively). Hydraulic conductivity, total porosity, and microporosity have the highest value at 0% pollution (13.10 cmhr^{-1}, 47.68%, and 43.85% respectively), then there was a decrease at 10% (4.70 cmhr^{-1}, 40.24%, 35.71% respectively) and a decreased further at 20% (4.60cmhr^{-1}, 39.58%, 35.21% respectively).

For soil type (Table III, Figure II), all physical properties are significant ($p<0.05$) except hydraulic conductivity, aggregate stability, and mean weight diameter which is non-significant. Generally, the results showed that the sandy clay loam soil has the highest bulk density (1.59 gcm^{-3}) and intermediate value for total porosity and macro porosity (40.88%, 4.23% respectively) and the lowest value for microporosity and state of aggregation (35.79%, 51.80%) when compared with other soils. The loamy sand soil has the lowest bulk density (1.43 gcm^{-3}) and macro porosity (2.86%), the highest total porosity (46.01%) and microporosity (43.15%), and an intermediate value (69.10%) for the state of aggregation when compared with other soils. The sandy loam soil also has the highest state

Table III. The main effects of soil type on the physical properties of the soil.

Soil type	Ks ($cmhr^{-1}$)	BD (gcm^{-3})	TP (%)	Macp (%)	Micp (%)	AS (%)	SA (%)	MWD (mm)
Sandy clay loam	8.70	1.59	40.88	4.23	35.79	72.64	51.80	2.15
Loamy sand	8.50	1.43	46.01	2.86	43.15	72.41	69.10	2.06
Sandy loam	5.20	1.57	40.61	4.77	35.84	72.90	71.20	2.08
F-$LSD_{0.05}$	N. S	0.06	1.01	1.17	2.64	N. S	3.92	N. S

Note: Ks = saturated hydraulic conductivity, BD=bulk density, TP= total porosity, AS = aggregate stability, SA = state of aggregation, Macp = macro porosity, Micp = microporosity, MWD =mean weight diameter.

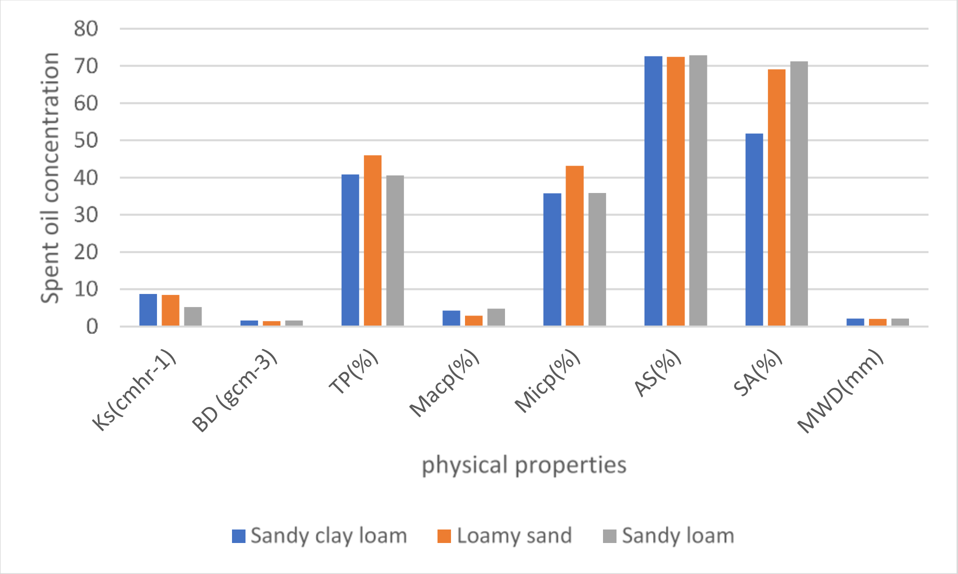

Figure II. The Main effects of soil type on the physical properties of the soil.

Table IV. The main effect of spent engine oil on the chemical properties of the soil.

Ps%	P ($mgkg^{-1}$)	CEC ($cmolkg^{-1}$)	N (%)	OM (%)	pHH_2O	pHKCl
P0	22.23	60.98	0.10	1.36	4.88	4.25
P10	27.02	33.33	0.15	29.16	5.49	4.82
P20	26.43	35.05	0.16	31.52	5.55	5.01
F-$LSD_{0.05}$	N. S	4.76	0.01	3.43	0.04	0.05

Note: OM = organic matter, CEC = cation exchange capacity, N= nitrogen, P = phosphorus, Ps = pollution status, p0 = 0% pollution, p10 = 10% pollution, p20 = 20% pollution.

of aggregation (71.2%) and macro porosity (4.77%), the lowest total porosity (40.61%), and an intermediate value for bulk density and microporosity (1.57 gcm^{-3}, 35.89% respectively).

All chemical properties (Table IV, Figure III) were significant ($p<0.05$) except available phosphorus which was non-significant. The cation exchange capacity decreases at a 10% pollution to 33.33 $cmolkg^{-1}$ and increases slightly at a 20% pollution rate to a value of (35.05 $cmolkg^{-1}$). Nitrogen, organic matter, and pH in water increase with an increased rate of pollution. At 0% pollution rate Nitrogen, organic matter, and pH in water have the lowest value (0.10%, 1.36%, 4.88 respectively, $p<0.05$) then at 10% there was an increase (0.15%, 29.16%, 5.49 respectively) and at 20% there was a further increase (0.16%, 31.52%, 5.55 respectively).

For Soil type (Table V, Figure IV), all chemical properties are significant ($p<0.05$) with sandy clay loam having the highest value of phosphorus (29.85 $mgkg^{-1}$), the lowest cation exchange capacity (33.51 $cmolkg^{-1}$), and an

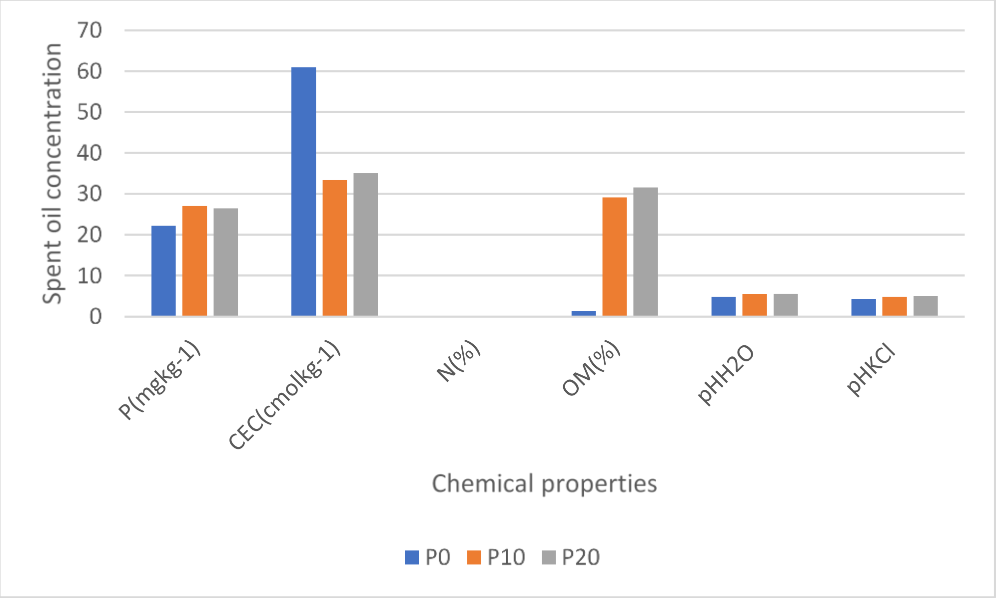

Figure III. The main effect of spent engine oil on the chemical properties of the soil.

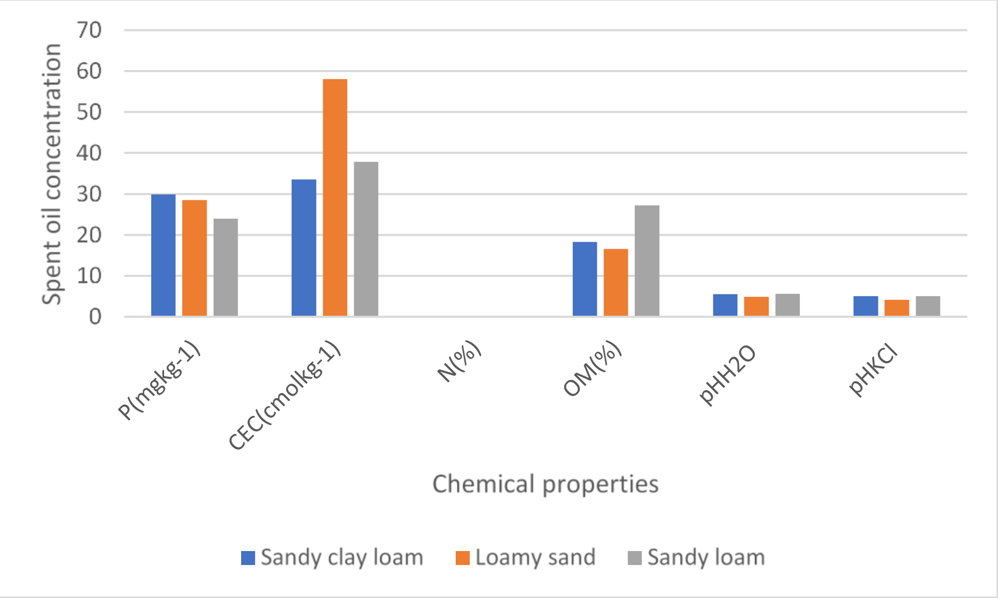

Figure IV. The main effect of soil type on the chemical properties of the soil.

Table V. The main effect of soil type on the chemical properties of the soil.

Soil type	P (mgkg^{-1})	CEC (cmolkg^{-1})	N (%)	OM (%)	pHH_2O	pHKCl
Sandy clay loam	29.85	33.51	0.15	18.23	5.49	5.00
Loamy sand	28.51	58.03	0.11	16.59	4.85	4.10
Sandy loam	23.99	37.82	0.16	27.21	5.58	5.01
F-LSD$_{0.05}$	5.44	11.73	0.02	3.23	0.03	0.06

Note: OM = organic matter, CEC = cation exchange capacity, N= nitrogen, P = phosphorus.

Table VI. Effects of the interaction of soil types and levels of spent engine oil pollution on the physical properties of soils.

Soil type	Ps%	Ks (cmhr^{-1})	BD (gcm^{-3})	TP (%)	Macp (%)	Micp (%)	AS (%)	SA (%)	MWD (mm)
	P0	16.6	1.47	44.69	4.18	40.44	51.69	41.50	1.30
SCL	P10	5.40	1.71	37.99	5.05	30.44	75.32	59.80	2.16
	P20	4.20	1.59	39.97	3.47	36.5	90.93	54.50	2.10
	P0	12.20	1.34	49.30	2.02	47.28	42.85	39.30	0.97
LS	P10	6.80	1.46	44.55	2.13	42.42	85.59	83.00	2.57
	P20	6.60	1.48	44.17	4.43	39.74	88.78	84.30	2.64
	P0	10.60	1.35	49.06	5.22	43.84	41.13	40.00	1.08
SL	P10	2.00	1.64	38.17	3.89	34.28	86.18	84.20	2.57
	P20	3.00	1.73	34.60	5.20	29.40	91.39	89.50	2.91
F-LSD$_{0.05}$		4.4	0.1	3.47	N. S	N. S	7.29	7.68	0.25

Note: Ks = saturated hydraulic conductivity, BD = bulk density, TP = total porosity, AS = aggregate stability, SA = state of aggregation, Macp = macro porosity, Micp = microporosity, MWD = mean weight diameter, SCL = sandy clay loam, LS = loamy sand, SL = sandy loam, p0 = 0% pollution, p10 = 10% pollution, p20 = 20% pollution.

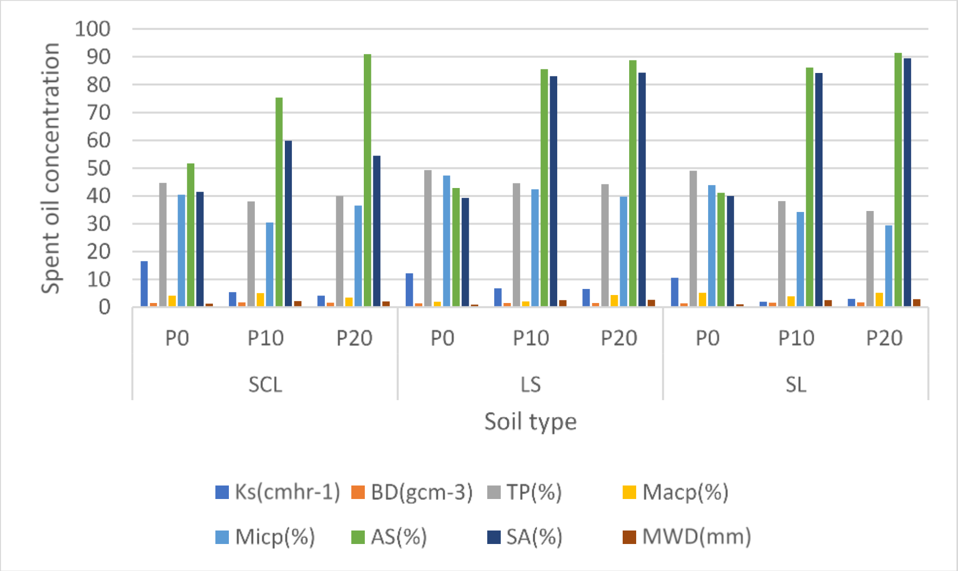

Figure V. Effects of the interaction of soil types and levels of spent engine oil pollution on the physical properties of soils.

intermediate value for nitrogen, organic matter, and pH in water (0.15%, 18.23, 5.49). Loamy sand soil has an intermediate value of phosphorus (28.51 mgkg^{-1}) when compared to other soil types, the highest cation exchange capacity (58.03 mgkg^{-1}), and the lowest nitrogen, organic matter, and pH in water (0.11%, 16.59%, 4.85 respectively). Sandy loam has the lowest phosphorus (23.99 mgkg^{-1}), an intermediate value of cation exchange capacity (37.82 cmolkg^{-1}), and the highest nitrogen, organic matter, and pH in water (0.16%, 27.21%, 5.58 respectively). Tables VI and VII and Figures V and VI show the different interactions.

DISCUSSION

In the present study, an increased concentration of spent engine oil leads to a decreased hydraulic conductivity (Table II, Figure I). This could be because of the clumping of the spent engine oil polluted soil thereby preventing the easy flow of water as spent engine oil is a viscous liquid that remains in the soil matrix. Agbogidi and Enujeke (2012) noted that soil polluted with spent engine oil experienced reduced water infiltration and percolation implying that less water will be available to the plant roots for photosynthesis. Bulk density increased (Table II, Figure I) and can be

Table VII. Effects of the interaction of soil types and different levels of spent engine oil pollution on the chemical properties of soil.

Soil type	Ps%	P (mgkg^{-1})	CEC (cmolkg^{-1})	N (%)	OM (%)	pHH$_2$0	pHKCl
SCL	P0	30.16	59.73	0.13	2.34	5.03	4.60
	P10	29.07	21.33	0.16	23.72	5.90	5.20
	P20	30.31	19.47	0.14	28.63	5.54	5.10
LS	P0	8.08	73.07	0.06	0.38	4.40	3.50
	P10	11.11	46.67	0.12	17.14	4.90	4.30
	P20	24.56	54.36	0.15	32.26	5.24	4.50
SL	P0	28.45	50.13	0.11	1.35	5.21	4.70
	P10	40.88	32.00	0.16	46.63	5.67	5.00
	P20	24.40	31.33	0.19	33.65	5.86	5.40
F-LSD$_{0.05}$		11.96	0.03	5.41	0.06	0.09	0.93

Note: OM = organic matter, CEC = cation exchange capacity, N = nitrogen, P = phosphorus, SCL = sandy clay loam, LS = loam sand, SL = sandy loam, p0 = 0% pollution, p10 = 10% pollution, p20 = 20% pollution.

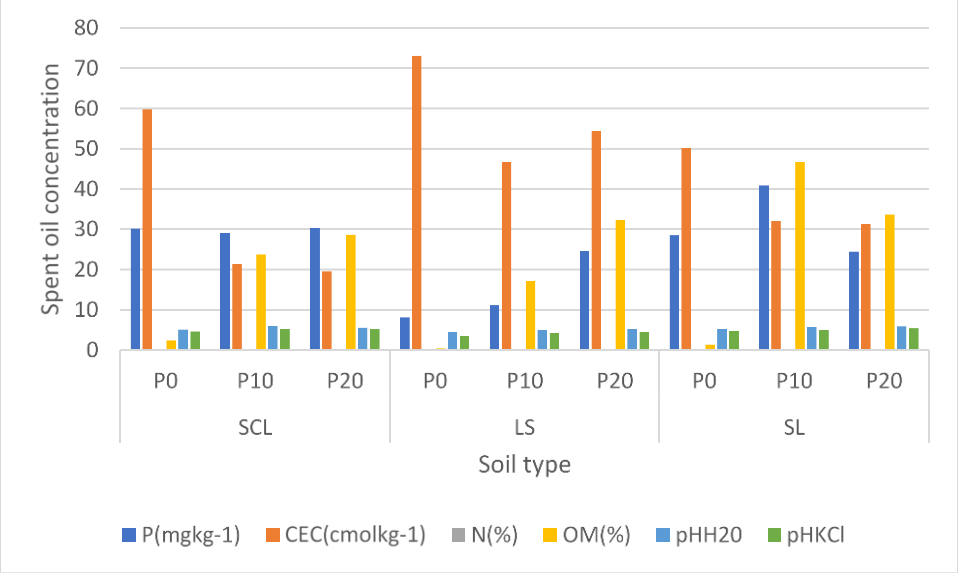

Figure VI. Effects of the interaction of soil types and different levels of spent engine oil pollution on the chemical properties of soil.

attributed to the soil compaction and the poor porosity of the polluted soil (Kayode et al. 2009; Nwite and Alu, 2015). The total porosity which is a function of the macro porosity and microporosity also decreased (Table II) (Vwioko *et al*., 2006) in the polluted soil due to clogging of the micro pores preventing the storage of water due to blockages (Nwite, 2013). Also, the oil displaces air and water leading to anaerobic conditions (Atlas and Raymond, 1977). The hydrophobic nature of crude oil reduces the permeability of air and water because it coats the soil particles and blocks soil pores thereby affecting soil water content (Wang *et al*., 2013). The increase in aggregate stability, state of aggregation, and mean weight diameter can be due to the increased organic matter in the soil which is a function of the large carbon-carbon chain in hydrocarbon, Coca-Salazar *et al*., (2022), experienced similar results which were discovered to be due to slower aggregate turnover thereby allowing the formation of organo-mineral associations and increasing the amount of less accessible carbon readily not available for decomposition by microorganism (Tobiašová *et al*., 2016).

Pollution of the soil with spent oil has no significant effect on the phosphorus content of the soil (Table IV, Figure III), Onyegeme-Okerenta *et al*. (2015) noted a significant reduction ($p<0.05$) in the concentration of soil phosphate in the control soil when compared to the polluted soils. The uptake of phosphate by plants via translocation might have been restricted accordingly with increasing spent engine oil pollution in the soil samples. Hence, resulting in the accumulation of phosphate in the polluted soils. The increase in nitrogen and organic matter (Table IV, Figure III) may be attributed to the high carbon hydrocarbon and the content of minerals in the oil (Nwite and Alu, 2015; Stephen and Ijah, 2011; Stephen and Eugene, 2012). According to Chijioke and Chinenye (2016), the total organic carbon (TOC) contents of the contaminated samples are expectedly higher than in the controls because of the hydrocarbon in those samples which has increased the bulk of carbon and organic matter. The cation exchange capacity which measures how many cations can be retained on the soil particle surface was higher in the unpolluted soil (Table IV, Figure III) indicating its ability to retain more nutrients and to supply important elements like magnesium, calcium, and potassium to the soil than the polluted soil. Even with the high organic matter, pH, and nitrogen in the polluted soil, there is still a decrease in the cation exchange capacity as the pollution rate increases and this could be attributed to the retainment of the minerals of the spent crude oil on the soil particle surface by removing the negative charge ions which are supposed to be in the soil particles surface which could also be as a result of the decrease in the acidity of the soil due to increasing pollution rate (Uhegbu *et al*., 2012).

All chemical and physical properties of the soil studied (Table III, Figures II, IV and V) undergo defects with spent engine oil treatment posing a threat to sustainable agriculture if not resolved. The parameters for polluted Loamy sand soil on bulk density, total porosity, macro porosity and microporosity, cation exchange capacity, nitrogen, and pH were within the range of that 0% pollution rate. The bulk density value of the polluted loamy sand soil (Table III, Figure II) was not above the critical limit for soil productivity (Grossman and Berdanier, 1982), and this could be a result of the high percentage of coarse sand in loamy sand soil thereby reducing compaction in the presence of spent engine oil (Tanimu *et al*., 2019). The hydraulic conductivity was higher for loamy sand soil at 10% and 20% than for sandy clay loam and sandy loam soil at 10% and 20% (Table III, Figure II) because due to the high percentage of silt and clay in sandy clay loam and sandy loam soil, the spent crude oil causes the sandy clay loam and sandy loam soil to form a clumpy matrix thereby preventing easy passage of water through the soil. However, the bulk density was higher for sandy clay loam and sandy loam soil at 10% and 20% because the bulk density of soil increases with increased compaction. The total porosity was higher for the polluted loamy sand soil compared to other polluted soil types because of the high percentage of coarse sand in the loamy sand soil and because of the high clay and silt percentage in sandy clay loam and sandy loam soil, the spent crude oil which is viscous causes the sandy clay loam and sandy loam soil to pack and clump thereby blocking the pore spaces. The loamy sand soil at 10% and 20% pollution has the lowest phosphorus, organic matter, and nitrogen, the most cation exchange capacity, and was more acidic (Table V, Figure IV) which can be attributed to the higher amount of coarse sand and fine sand in the soil. In contrast to Osaigbovo *et al*., (2013), spent engine oil-polluted sandy clay loam soil showed no significant effect on total nitrogen. The best interaction (Tables VI and VII, Figures V and VI) was loamy sand soil at 0% and 10% pollution.

Conclusion

The effects of spent engine oil on the soil are a challenge to the soil health, it prevents the soil from anchoring and supplying nutrients needed for plant growth thereby posing a threat to food security and sustainable agriculture. The polluted loam sand soil portrayed a low bulk density, high total porosity, low macro porosity, and high microporosity compared to the other soils. Also, the polluted loamy sand soil has a higher cation exchange capacity but lower phosphorus, nitrogen, organic matter, and pH. The effect of the spent engine oil was higher on the 20% polluted sandy clay loam soil. Overall, the results showed that the loam sand soil can still withstand the growth of sunflower plants at a 10% pollution rate. Phytoremediation, which uses plants to remediate, and bioremediation which uses soil microorganisms to remediate soils can help solve the problems of crude oil spillage. Hence, research in these areas is required to know the best remediation method.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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