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PHYSICAL PROPERTIES AND MAIZE PRODUCTION IN A SPENT OIL-CONTAMINATED SOIL BIOREMEDIATED WITH LEGUMES AND ORGANIC NUTRIENTS

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ABSTRACT

Information on the use of plant species and organic nutrients to improve the physical properties of oil-contaminated soil, with a view to making it conducive for crop production, is very important. Three legumes (Gliricidia sepium, Leucenae leucocephala and Calapogonium caeruleam) combined or not with poultry manure were tested for their ability to improve the physical properties of a sandy soil, contaminated with 5% (w/w) spent lubricating oil, each for two years, and its effects on the growth and yield of maize in south eastern Nigeria. Aggregate stability (MWD), saturated hydraulic conductivity, and macro-to micro-porosity ratio improved with time in all the treatments over the 5% oil contamination (A_5) and control. At 12 and 18 months, the use of Gliricidia sepium with 0.5% (w/w) poultry manure (A_5+Gl+PM) gave the highest improvement of 58% and 94% in MWD, corresponding to 136% and 187% improvement in saturated hydraulic conductivity, respectively over the A_5. The A_5+Gl+PM also enhanced soil aggregate sizes > 0.25 mm by 63.6% and showed a 3-fold positive modification in soil macro-porosity. Positive relationships, significant at 0.01 level of probability, were observed between crusting hazard (R) and soil organic matter (r = 0.814), micro-porosity (r = 0.686) and saturated hydraulic conductivity (r = 0.787). The A_5+Le+PM also increased maize growth and grain yield. Gliricidia sepium and Leucenae leucocephala combined with 0.5% (w/w) poultry manure is recommended for follow-up investigation, as it may offer a viable choice for remediation of oil-contaminated soil.

Keywords: Bioremediation, oil-contamination, legumes, soil physical properties, maize growth and yield.

INTRODUCTION

The global emphasis on soil health and sustainable food security is persuading soil scientists to consider rehabilitation of degraded lands, especially where oil-contamination limits the use of such soils. The indiscriminate discharge of petrol oils and grease into farmlands, open vacant plots and water drains is becoming an acute environmental problem in Nigeria, particularly when large areas of agricultural land are contaminated (Atuanya, 1987). Government efforts to monitor, control and/or regulate these activities have proven to be very difficult because of paucity of information on the incidence of these activities Thus, contamination of agricultural ecosystems arising from discharge of petrol oils and grease with significant levels of hydrocarbons and other properties present in all petroleum products is more widespread than crude oil pollution (Atuanya, 1987).

Depletion in the nutrient status (nitrogen and phosphorus), inhibition of microbial activities and degradation of soil physical properties have been reported in spent oil impacted soils (Atlas and Bartha, 1993; Kirk *et al.*, 2005). Formation of waxy texture in soils contaminated with spent lubricating oil has been

(Anoliefo and Vwioko, 1995). The formation of oily scum which impedes oxygen and availability of water to biota as well as the formation of hydrophobic micro-aggregates with clay surfaces (Amadi *et al.*, 1993; Rasiah *et al.*, 1990), are associated with oil-contaminated soils. Decrease in soil water retention capacity at high potential (-10 to –200 KPa) as a result of oil succeeding water in the competition for pore spaces and reduction in water film thickness around macro-aggregates, are a few other effects of oil in soil (Rasiah *et al.*, 1990).

The use of green plants and organic nutrients to reclaim soils contaminated with petroleum products has recently become a subject of intense scientific interest in bioremediation technologies. However, the major focus has been on heavy metal attenuation and other chemical properties (Merkl *et al.*, 2005; Harayama *et al.*, 2004; Gallizia *et al.*, 2003). Information regarding the use of some legumes and organic nutrient to improve the physical properties of oil-contaminated soil, with a view to making it available for crop production, is limited.

To evaluate the impact of bioremediation techniques on oil-contaminated soils, it is necessary to quantify the modifications in the soil physical properties, since they are the most important properties affecting crop production. Hence, the objective of this study was to evaluate the impact of three legume plants combined or not with poultry manure on the physical properties of spent lubricating oil-contaminated soil and relate such changes to maize performance. Furthermore, since the selected legume plants comprise widespread cultivated species, results have worldwide importance in countries beyond Nigeria.

MATERIALS AND METHODS

This study was carried out on 45 plots (each measuring 2.5 x 1.5 m) at the University of Nigeria, Nsukka, Research Farm (Lat. 06^0 52'N, and Long.07^0 24'E). The soil is sandy loam (*Typic Kandiustult*) (Nwadialo, 1989) with low organic matter (Table 1). The plots were impacted with equivalent of 50,000 mg kg-,^{1} (5% w/w) mono-and multi-grade crankcase oils from petrol and diesel engines, together with gear oils and transmission fluids and applied in a single dose each for two years. By the second year, oil contaminated plots had spent oil application of 100,000 mg kg-^{1} representing a total oil load of 10% (w/w). Three (3) legumes: *Calapogonium caerulean, Gliricidia sepium,* and *Leucaena leucocephala* combined or not with equivalent of 500 mg kg^{-1} (0.5% w/w) of poultry manure were used to enhance biodegradation.

Table 1: Some physical properties of the top (0.30cm) soil of the experimental sit- poultry manure and spent lubricating oil.

Parameter	Units	Soil	PM	SP
Sand (2000-50μm)	g kg^{-1}	820	-	-
Silt (50-2μm)	g kg^{-1}	60	-	-
Clay (<2μm)	g kg^{-1}	120	-	-
Texture	-	Sandy loam	-	-
Saturated Hydraulic conductivity	Cm hr^{-1}	20.44	-	-
Aggregate stability (MWD)	Mm	1.443	-	-
Bulk density	g cm^{-3}	1.52	-	-
Water holding capacity	cm^{-3} cm^{-3}	0.31	-	-
Micro-porosity	%	29.7	-	-
Macro-porosity	%	22.0	-	-
Specific gravity	-	-	-	0.874
Organic matter	g kg^{-1}	5.98	23.63	-

PM – poultry manure, SP- spent lubricating oil.

The experiment was arranged as a Randomized Complete Block Design (RCBD), with nine (9) treatments, viz: uncontaminated (control) soil (C), 5% spent oil (A_5), 5% spent oil + *Calapogonium spp.* (A_5+Ca), 5% spent oil + *Gliricidia spp* (A_5+Gl), 5% spent oil + *Leucenae spp* (A_5 +Le), 5% spent oil + *Calapogonium spp.* + 0.5% poultry manure (A_5+Ca+PM), 5% spent oil + *Gliricidia* + 0.5% poultry manure (A_5+Gl+PM), 5% spent oil + *Leucaena spp.* + 0.5% poultry manure (A5+Le+PM) with five replications. The legume seeds and poultry manure were introduced during early rains to the plots, seven (7) days after the oil contamination and allowed to incubate for fourteen (14) days before planting the maize crop. The second application of 5% spent oil was done 360 days after the first application.

Sampling

Disturbed and core soil samples were collected from the 0-30 cm depth at 3, 6, 12, 18, and 24 months after oil application, for measurement of some physical properties. The implications of the oil and legume treatments on maize performance were evaluated at the crop's growth stage using plant height and grain yield, viz: 0-establishment (10% of vegetative cover) (28-30 DAP), 1 – vegetative phase (80% of vegetative cover) (40-48 DAP) 2- tassel (65-72 DAP), 3 -

cob setting/ filling (93-96 DAP), and 4 - grain yield at maturity.

Laboratory Studies

Water-Stable Aggregates and Aggregate Stability

Water- stable aggregate was measured by the Kemper and Rosenau (1986) wet-sieving method. In this procedure, 40 g soil samples of < 4.75 mm aggregates were placed on the top of a nest of sieves of diameters 2, 1, 0.5 and 0.25 mm, and presoaked in distilled water for 30 min before oscillating vertically once per second in water for 20 times, using a 4 cm amplitude. The percentage ratio of the resistant aggregates on each sieve, representing the water-stable aggregates (WSA), was calculated as:

$$WSA = (MR/MT) \times 100 \quad \ldots (1)$$

where, MR is the mass of resistant aggregate (g), and MT, the total mass of wet-sieved soil (g). Aggregate stability was measured by the mean-weight diameter (MWD) of water- stable aggregates (Kemper and Rosenau, 1986), calculated as:

$$MWD = \sum_{i-1}^{n} X_i W_i \quad \ldots (2)$$

where, X_i is the mean diameter of each size fraction (mm), and W_i is the proportion of the total aggregate in each size fraction and n is the number of sieves used. The State of Aggregation (SOA) was calculated using the Yoder (1936) method as:

$$SOA = A/Y \quad \ldots (3)$$

where, A is the aggregated particles with diameter > 0.25 mm and Y the original weight of oven-dried soil.

Pore-Size Distribution, Saturated Hydraulic Conductivity and Crusting Hazard.

Pore-size distribution was calculated using the Flint and Flint (2002) water retention data. Saturated hydraulic conductivity (K_{sat}) was determined by the constant head permeameter technique (Klute and Dirksen, 1986) as:

$$\frac{QL}{AT. \Delta H} \quad \ldots (4)$$

where, Q is volume of water (cm^3) that passed through a cross sectional area, A (cm^2), T is time elapsed (sec.), L is length of core (m), A is the cross sectional area of the core (cm^2) and ΔH is hydraulic head difference (cm). Crusting hazard (risk of sealing) "R" was calculated and classified using the Van der Watt and Claassen's (1990) procedure as:

$$R\ (\%) = \frac{\text{Organic matter} \times 10}{(\text{Clay} + \%\ \text{silt}} \quad \ldots (5)$$

Values $\leq$ 5% were considered high, 7% threshold value and $\geq$ 9%, low.

Total organic carbon (TOC) was measured by the Walkley and Black wet dichromate oxidation method (Nelson and Sommers, 1982) and converted to OM by multiplying the organic matter (OC) values by 1.724.

Table 2: Aggregate stability (MWD) of the top 0.30 cm of the oil contaminated soil as influenced by the treatment after 24 months.

	MWD (mm)					
Treatment	3	6	12	18	24	Mean
A_5	1.718	0.880	0.871	0.803	0.850	1.024
A_5+ Gl	1.322	1.096	1.261	1.473	1.473	1.306
A_5 + Le	1.390	0.861	1.126	1.416	1.416	1.215
A_5 + Ca	1.351	0.873	1.117	1.492	1.492	1.213
A_5 + PM	1.303	1.126	1.211	1.411	1.411	1.277
A_5 + Gl + PM	1.253	1.087	1.380	1.720	1.720	1.400
A_5 + Le + PM	1.316	1.270	1.500	1.526	1.526	1.319
A_5 + Ca +PM	1.245	1.066	1.221	1.480	1.480	1.261
C	1.361	1.290	1.242	1.086	1.086	1.208
Mean	1.362	1.061	1.175	1.384	1.384	-

LSD) (0.05 Treatment = 0.082; Month= 0.11, Tx M = 0.041 C = control, A_5= 5% (w/w) spent oil, Gl = Gliricilia spp, Le= Leucaena spp Ca= Calapogonium spp, PM = 0.5% (w/w) poulty manure.

Table 3: Saturated hydraulic conductivity (cm hr^{-1} of the top 0.30 cm of the oil – contaminated soil as influenced by the treatment after 24 months.

	months after oil application					
Treatment	3	6	12	18	24	Mean
A_5	10.15	9.74	9.88	8.64	9.91	9.66
A_5+ Gl	13.08	15.99	20.74	20.98	20.99	18.36
A_5 + Le	14.43	16.11	15.69	17.10	17.59	16.18
A_5 + Ca	13.78	15.25	15.01	20.68	20.95	17.13
A_5 + PM	19.47	20.98	23.76	23.40	23.68	22.26
A_5 + Gl + PM	20.64	22.19	23.28	24.77	24.96	23.17
A_5 + Le + PM	20.25	20.96	23.78	23.45	23.99	22.49
A_5 + Ca +PM	20.51	21.67	22.71	23.24	23.11	22.25
C	21.81	20.90	20.64	20.79	20.67	20.96
Mean	17.12	18.20	19.50	20.34	20.35	-

LSD (0.05) Treatment = 1.22, Months = 1.636, T x M = 0.545
K_{sat}= Saturated hydraulic conductivity

Table 4: The state of aggregation (%) of the top 0-30 cm of the oil-contaminated soil as influenced by the treatments after 24 months.

	Months after oil application					
Treatment	**3**	**6**	**12**	**18**	**24**	**Mean**
A_5	59.5	44.8	44.6	43.7	42.3	57.0
A_5 + Gl	52.5	52.6	52.8	61.2	63.9	56.6
A_5 +Le	53.4	54.1	55.7	63.8	64.0	58.2
A_5+Ca	53.6	52.3	60.8	62.1	63.4	58.4
A_5 + PM	54.8	59.8	60.0	63.6	65.2	60.7
A_5+ Gl + PM	53.7	55.0	68.3	70.2	70.6	63.6
A_5 + Le+ PM	53.2	59.0	61.0	63.5	66.0	60.3
A_5 + Ca + PM	56.8	58.6	60.4	62.4	65.4	60.7
C	55.0	53.4	48.5	46.8	41.7	49.1
Mean	54.7	54.4	56.9	59.7	60.2	-

LSD (0.05) Treatment = 4.252, Months = NS, T x M = NS

RESULTS AND DISCUSSION

Aggregate Stability and Hydraulic Conductivity.

The mean weight diameter (MWD) of water stable agregates improved with time in all the treatments except in A_5 (soil contaminated with 5% spent oil without legumes and poultry manure) and in C (control soil) (Table 2). The MWD decreased from 1.718 mm at 3 months to 0.850 mm at the 24 months in the A_5, with marginal decreases from 1.361 to 1.242 mm in the control during the same period. At 12 and 18 months, the A_5+Gl+PM gave the highest improvement of 58% and 94%, in MWD, respectively, and corresponding increases of 136% and 187% in saturated hydraulic conductivity over the A_5 (Table 3). This improvement shows that the use of *Gliricidia sepium* with 0.5% poultry manure is very effective in bioremediation of aggregate stability and saturated hydraulic conductivity of spent–oil-contaminated soil. Saturated hydraulic conductivity, as low as 8.64 cm hr^{-1}, obtained for A_5 at 18 months (Table 3) indicates that the oil succeeded water in the competition for pore spaces, leading to reduction in water film thickness around macro-aggregates (Rasiah *et al.*, 1990). Also, the relatively high value of 1.718 mm in MWD (Table 2), without corresponding increase in saturated hydraulic conductivity (10.15 cm hr^{-1}) at 3 months (Table 3), was not surprising, as this may have been due to the formation of hydrophobic macro-aggregates reported for similar soils by Amadi *et al*; (1993) and Kirk *et al.*,. (2005). After 24 months, the average improvement in aggregate stability was in the order of A_5+Gl+PM > A_5+Le+PM > A_5+Gl > A_5+Gl > A_5+PM > A_5+Ca+PM > A_5+Le > A_5+Ca > C > A_5 (Table 2), whereas saturated hydraulic conductivity was increased in the order of A_5+Gl+PM > A_5 + Le+PM > A_5+PM > A_5+Ca+PM > A_5 (Table 3). Therefore, a combination of 0.5% poultry manure with *Gliricidia sepium* and *Leucaena leucocephala* positively improved both aggregate stability and saturated hydraulic conductivity of the spent oil-contaminated soil. Poultry manure with *Gliricidia* (A_5+Gl+PM) enhanced soil aggregate sizes > 0.25 mm by 63.6% (Table 4). The use of poultry manure alone (A_5+PM) led to improvement of 60.7% of aggregate sizes > 0.25 mm, indicating the effectiveness of poultry manure and *Gliricidia sepium* in improving aggregate sizes of these degraded soils.

Table 5: Pore-size distribution of the top 0-30cm of the oil-contaminated soil as influenced by the treatments after 24 months.

	Micro-porosity (%) Months after oil application					
Treatment	**3**	**6**	**12**	**18**	**24**	**Mean**
A_5	36	34	37	31	39	35
A_5 + Gl	27	25	25	22	22	24
A_5 +Le	27	27	25	25	24	26
A_5+Ca	26	25	24	23	23	24
A_5 +PM	25	23	23	22	22	23
A_5+Gl +PM	24	24	22	22	21	23
A_5 + Le+ PM	24	23	22	23	22	23
A_5 +Ca +PM	26	25	21	21	21	23
C	24	27	26	25	27	25
Mean	27	26			25	24
	Macro-porosity (%)					
Treatment	**3**	**6**	**12**	**18**	**24**	**Mean**
A_5	9	8	8	7	7	8
A_5 + Gl	13	13	26	27	27	21
A_5 +Le	11	14	16	23	26	18
A_5+Ca	12	14	16	24	25	18
A_5 +PM	14	14	20	26	23	19
A_5+Gl +PM	16	19	20	21	22	19
A_5 + Le+ PM	14	16	20	21	22	19
A_5 +Ca +PM	15	15	21	21	23	19
C	26	14	14	13	12	16
Mean	14	14	19	21	21	-

LSD (0.05) Micro-porosity: Treatment = 3.311, Months 2.591, T x M = 3.417 Macro-porosity : Treatment = 7.149, Months = NS, T x M = NS

Table 6: Organic matter (g Kg^{-1}) of the top 0-30cm of the oil contaminated soil as influenced by treatments after 24 months

	Months after oil application					
Treatment	**3**	**6**	**12**	**18**	**24**	**Mean**
A_5	24.2	21.0	19.5	19.5	19.2	20.7
A_5 + Gl	19.6	19.8	20.1	22.0	23.0	21.1
A_5 +Le	19.5	19.6	19.8	21.4	22.3	20.5
A_5+ Ca	16.9	17.2	19.4	22.1	23.3	19.8
A_5 + PM	20.6	21.4	17.2	21.1	23.7	20.8
A_5+ Gl + PM	19.8	23.1	23.6	23.0	26.3	23.2
A_5 + Le + PM	17.8	21.4	22.6	23.0	24.0	21.8
A_5 + Ca + PM	19.4	22.8	23.2	23.8	24.0	22.6
C	14.3	13.6	13.0	13.1	13.9	13.4
Mean	19.1	20.0	19.8	21.0	22.2	-

Table 7: Crusting hazard (%) of the top 0-30 cm of the oil-contaminated soil as influence by treatments after 24 months.

	Months after oil application					
Treatment	**3**	**6**	**12**	**18**	**24**	**Mean**
A_5	13	9	6	7	7	8
A_5 + Gl	10	11	9	10	10	10
A_5 +Le	8	9	10	11	10	10
A_5+ Ca	7	7	10	13	10	9
A_5 + PM	10	10	8	10	11	10
A_5+ Gl + PM	9	11	10	10	12	10
A_5 + Le + PM	10	10	10	11	12	11
A_5 + Ca + PM	9	12	10	11	12	11
C	12	6	6	6	6	7
Mean	10	9	8	10	10	-

LSD (0.05) Treatment = 1.440, Month = NS,T x M = NS

Pore Size Distribution, Organic Matter and Crusting Hazard

Macro-porosity for A_5 soil was low, ranging from 7-9% (Table 5). The low macro- to micro-porosity in the A_5 soil was probably due to the formation of waxy texture by the oil (Anoliefo and Vwioko, 1995), which may impede oxygen and available water content of the soil. The *Gliricidia sepium,* in combination with 0.5% poultry manure (A_5+Gl+PM), showed a 3-fold positive modification in soil macro-porosity over the A_5 at 18 and 24 weeks (Table 5). The positive role of *Gliricidia* and *Leucaena* spp. in enhancing the macro-porosity could be attributable to their ability to improve the soil organic matter (SOM) content (Table 6) and the influence of their root exudates on the rhizosphere soil (Merkl *et al.*, 2005, Molina-Barahona *et al.*, 2004). A combination of poultry manure with *Gliricidia spp, Calapogonuim* spp. *and Leucaena spp* improved the average soil organic matter by 23.2, 22.6 and 21.8 g Kg^{-1} , respectively after 24 months (Table 6), with concomitant reductions in crusting hazard of 11,11 and 10%, respectively compared with A_5 and the control (Table 7). The low average macro-porosity (8%) recorded for A_5 (Table 5) may result in the formation of structural crusts which according to West *et al.* (1992), is considered the best indicator of soil structure conditions as well as a realistic basis for understanding water movement in the soil, to assess the suitability of such soil for root growth and the activities and movement of soil organisms.

The correlation analysis (Table 8) showed a significant ($P < 0.01$) positive relationship ($r = 0.814$) between crusting hazard (R) and soil organic matter (SOM) content, confirming the positive role of SOM in reducing soil crusting. The significant ($P < 0.05$) positive correlation between R and macro-porosity ($r = 0.686$) and saturated hydraulic conductivity ($r = 0.787$) was not surprising. The explanations are that increases in R (low crusting hazard) lead to increases in saturated hydraulic conductivity and macro-porosity, indicating that soil organic matter, saturated hydraulic conductivity and macro-porosity were modified by the treatments, thus reducing crusting in plots treated with organic nutrient and legume plants. Pagliai (1987) has reported positive relationships amongst soil organic matter, aggregate stability and surface crusting.

Table 8: Relationship among some physical properties of the oil-contaminated soil

Soil parameters	OM (g Kg^{-1})	Micro porosity (%)	Macro porosity (%)	R (%)	K_{sat} (cm hr^{-1})
O.M (g kg^{-1})	1.0	-0.133^{ns}	0.326^{ns}	- 0.814**	0.356^{ns}
Micro porosity (%)		1.0	-0.918^{ns}	-0.669*	-0.912**
Macro porosity (%)			1.0	0.686*	0.767*
R (%)				1.0	0.787*

(N = 9)

ns = Not Significant at P > 0.05 * Significant at p < 0.05,
**Significant at P< 0.01, OM = Organic matter, R = Crusting hazard, Ksat = Saturated hydraulic conductivity.

Table 9: Mean plant height (cm) of maize plant in oil – contaminated soil under different treatments at different growth stages.

	Growth stages				
Treatment	**Establishment (28 DAP)**	**Vegetative (40 DAP)**	**Tasselling (65 DAP)**	**Cobsetting/Filling (91 DAP)**	**Mean**
A_5	15.8	39.3	42.5	44.7	35.6
A_5 + Gl	17.5	48.3	60.9	74.7	50.4
A_5 +Le	16.5	44.9	58.4	73.6	48.4
A_5+ Ca	16.4	53.4	56.6	62.4	47.2
A_5 + PM	26.4	122.4	130.3	156.6	108.9
A_5+ Gl + PM	31.1	134.5	142.2	134.7	115.6
A_5 + Le + PM	26.1	122.3	138.3	152.7	111.3
A_5 + Ca + PM	31.1	117.0	130.3	152.7	107.8
C	17.8	62.4	65.3	67.2	53.2
Mean	22.1	82.7	91.7	105.0	-
			2005		
	(30 DAP)	**(48 DAP)**	**(72 DAP)**	**(96 DAP)**	
A_5	7.4	9.0	0.0 (D)	0.0 (D)	4.1
A_5 + Gl	21.2	37.0	55.2	67.9	45.3
A_5 +Le	19. 4	29.0	54.1	58.3	40.2
A_5+ Ca	14.9	51.7	56.9	63.2	41.7
A_5 + PM	52.8	59.8	126.5	141.0	95.0
A_5+ Gl + PM	53.3	72.7	137.8	166.5	107.6
A_5 + Le + PM	49.9	71.8	128.0	144.2	98.5
A_5 + Ca + PM	48.8	64.3	143.9	152.8	102.5
C	12.3	13.4	28.7	34.5	22.2
Mean	31.1	43.2	81.2	92.0	-

2004: LSD (0.05) Treatment = 21. 740, Growth Stages = 34. 003, T x GS = 28. 636.
2005: LSD (0.05) Treatment = 25.02, Growth Stages = 41. 86, T x GS = 14. 446, D = Death

Effect of Treatments on Crop Performance

The maize plant was adversely inhibited during the establishment and vegetative growth stages. When the oil load was increased to 10% (w/w) in the second planting year, the plants died before 72 DAP (Table 9). Several factors may have contributed to the death of the plants, among which may include: lack of adequate oxygen, decrease in soil water retention capacity, surface crusting, and other undesirable soil physical conditions. Similar observations have been made by Anoliefo and Vwioko (1995) in pepper (*Capsicum annum* L.) *and tomato* (*Lycopersicon esculentum* Miller) and for maize and sugar cane (Molina-Barahona, 2004). Plant growth was higher (115.6 and 107.6 cm) for A_5+Gl+PM during the first and second plantings, respectively (Table 9). Grain yield of 4.91 t ha^{-1} obtained during the first planting and 8.25 t ha^{-1} during the second planting for A_5+Gl+PM gave significantly ($p < 0.05$) higher yield than using the legume plants alone (A_5+Gl, A_5+Le, or A_5+Ca). (Table 10).

Table 10: Effects of treatments on grain yield of maize Maize grain yield (t ha^{-1})

Treatment	2004	2005
A_5	NY	Ny
A_5 + Gl	3.06^b	5.16^b
A_5 +Le	2.32^a	5.05^b
A_5+ Ca	1.87^a	4.79^b
A_5 + PM	4.01^b	6.23^a
A_5+ Gl + PM	4.91^a	8.25^b
A_5 + Le + PM	3.91^b	6.90^a
A_5 + Ca + PM	4.16^b	7.02^a
C	NY	NY

Yields followed by different letters within the years are significantly different at $p<0.05$ NY = No Yield.

CONCLUSION

Based on these results, spent lubricating oil inhibited the growth of maize, during the establishment and vegetative growth stages, leading to the death of the plants. However, *Gliricidia sepium* and *Leucaena leucocephala,* if combined with 0.5% poultry manure, are promising alternatives for bioremediation of the physical properties of spent oil-contaminated soils. It is inexpensive, efficient and environmentally compatible, and may offer a viable choice for oil-contaminated soil remediation for maize production.

Additionally, they are well-known and easy-to-manage cultivated species, of which if accumulation of toxic oil compounds in the leaves can be excluded, *Gliricidia sepium and Leucaena leucocephala* with 0.5% poultry manure, could be used for the remediation of oil-contaminated soils.

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