Ameliorative effects of Daniellia- and Vitellaria-derived biochars on the chemistry of oil-contaminated soils and germination indices of cowpea

S. Oyedeji1*, O.C. Oloukun2, O.O. Agboola2, D.A. Animasaun1 and P.O. Fatoba1

1Department of Plant Biology, University of Ilorin, Ilorin, 240003 Nigeria
2Department of Botany, University of Lagos, Akoka, Lagos, Nigeria

Received:21/01/2018; Accepted:01/05/2018

Abstract: The study assessed the effectiveness of biochars derived from Daniellia oliveri and Vitellaria paradoxa in ameliorating waste lubricant oil contaminated soils and improving germination of cowpea seeds. Daniellia oliveri and Vitellaria paradoxa biochars were applied at 0.5 and 1.0 % levels to soils contaminated with 2 % v/w waste lubricant oil (WLO). The unpolluted soil and WLO-contaminated soil without biochar were also used as controls. All treatments in three replicates were arranged in a randomized block design in a screen house. Biochars and soils were analyzed for pH, organic carbon (OC), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) and total petroleum hydrocarbon (TPH exclusively analyzed for soil). Ten cowpea seeds sown in soils were observed for sprouting from 1 to 10 days after sowing (DAS). Germination percentage and indices were determined from the number of sprouted seeds at 10 DAS. Vitellaria-derived biochar (BV) had higher N, K and Mg than Daniellia-derived biochar (BD). WLO contamination significantly reduced soil P but slightly affected pH, OC and exchangeable cations. Addition of BD and BV reduced TPH and improved soil quality. Oil contamination delayed and reduced cowpea germination by 9.3 % in un-amended WLO-contaminated soil. 1 % BV addition was effective in improving germination velocity and indices of cowpea seeds in oil-contaminated soils.

Keywords: Biochar, cowpea, germination, soil improvement, waste lubricant oil.

INTRODUCTION

Soil pollution from petroleum derivatives, previously considered a problem of petroleum producing or processing countries, is fast becoming a global problem posing a starting challenge to non-petroleum producing countries as well (Odjegba and Sadiq, 2002). The surge in the number of automobiles has consequently increased the demand for automobile repairers (mechanics) who ignorantly dispose waste lubricant oils, after servicing engines, in gutters, water drains, open plots and farms (Lale et al., 2014). Oil contamination affects the biological, physical, chemical components of the soil in various ways (Atanaya, 1987; Odjegba and Sadiq, 2002; Agbogidi and Ejemeta, 2005: Agbogidi, 2010), and its effects on the growth, development, productivity and yield of plants cannot be undermined. Apart from the introduction of trace metals such as lead, nickel, zinc and barium, chemical additives such as amines, phenols, sulphur associated with waste lubricant oils (Lale et al., 2014) also contribute to impede growth and development of plants. Oil in soil creates anaerobic condition by impeding moisture content (Shukry et al., 2013), excluding air and increasing the production of hydrogen sulphide (Udo and Oputa, 1984) which ultimately induces considerable retardation in germination and plant growth (Adam and Duncan, 2002). Several authors have reported a lower rate of germination in soil contaminated by petroleum or its derivatives (Amakiri and Onofeghara, 1984; Adam and Duncan, 1999; Vavrek and Campbell, 2002; Méndez-Natera et al., 2004; Achuba, 2006; Smith et al., 2006; Sharifi et al., 2007; Korade and Fulekar, 2009; Bonà et al., 2011; Udom et al., 2012). Apart from seed germination impairment, reductions in yield and premature death of crops have also been reported in soils contaminated with waste lubricant oil (Udom et al., 2012). Since soil health is the foundation of a vigorous and sustainable food system, corrective measures are needed to alleviate the effects of contamination while improving crop production.

Various techniques, including the use of plants and/or associated microorganisms, have been studied to be efficient in ameliorating polluted soils through removal, inhibition or decontamination of harmful materials (Cunningham and Ow, 1996; Schwab and Banks, 1999; Merkl et al., 2005). Recent focus on biochar, a stable carbon-rich charred biomass and its utilization as a soil amendment (Qayyum et al., 2014) have proved highly effective due to its sorption ability for organic pollutants (Zhang et al., 2010) and heavy metals (Beesley et al., 2010). Biochar has been produced from numerous biological residues ranging from wood to manures and feedstocks to plant materials (Beesley et al., 2011). Although the use of charcoal (wood biochar) is common, biochar production using organic wastes or feedstocks such as wood waste, crop residues (including straw, nut shells, and rice hulls), switch grass, bagasse from the sugarcane industry, chicken litter, dairy manure, sewage sludge and paper sludge is relatively new. More recently biochar obtained derived from the number of sprouted seeds at 10 DAS. Germination percentage and indices were determined were observed for sprouting from 1 to 10 days after sowing (DAS).
from wheat residue (Yu et al., 2006), eucalyptus (Yu et al., 2009), Gossypium (Yang et al., 2010) and orchard prune residue (Fellet et al., 2011) have been tested as amendment on contaminated soils. Typically, biochars have high cation exchange capacity and with potential benefits in increasing soil biological activity (Lehmann et al., 2011; Paz-Ferreiro et al., 2014), diminishing soil greenhouse gas emissions from agricultural sources and thus enhancing soil carbon sequestration due to its elevated content of recalcitrant forms of carbon (Gascó et al., 2012). Biochar production through pyrolysis does not only offer a way of reducing air pollution from open burning of crop biomass, but also a favorable agriculture sustainable model for reutilizing agricultural waste (Wang et al., 2013). This residue conversion approach will be particularly useful in vegetation types,such as savannas, where most of the tree species are deciduous.

The present study assessed the effectiveness of biochars derived from Daniellia oliveri and Vitellaria paradoxa in ameliorating waste lubricant oil contaminated soils and improving germination of cowpea seeds. This is with the aim of sustainably utilizing the huge wastes of litters from these tree species, growing abundantly in savanna-type (Guinea, Sudan and Sahel) vegetation in Nigeria, in crop production, most especially cowpea which account for major protein in the diet of average Nigerians.

**MATERIALS AND METHODS**

Biochar was produced separately from leaf litters of Daniellia oliveri and Vitellaria paradoxa using a muffle furnace (Gallenkamp model) maintained at 450 °C. Chemical properties including pH, total organic carbon, total nitrogen, available phosphorus and exchangeable cations (K, Ca and Mg) of the biochars were determined using standard procedures. Biochar pH was determined in 1:2.5 w/v of biochar powder to 0.02M CaCl₂ solution. Organic carbon was determined using wet digestion method as outlined by Walkley and Black (1934). Total nitrogen was determined using macro Kjeldahl method of digestion, distillation and back titration (Bremner, 1996). Available P was determined using colorimetric method as outlined by Olsen and Sommers (1982). Potassium, calcium and magnesium concentrations were determined using filtrate of mixed acid (HClO₃-HNO₃) (Faridullah et al., 2014) digests read at 766.5 nm, 422.7 nm and 285.2 nm with atomic absorption spectrophotometer (Buck Scientific Model - 210VGP).

Soil was collected from 0 to 15 cm soil depth from an un-disturbed area in the Botanical Garden, University of Ilorin, Nigeria. Soils in the area are predominantly lateritic with loamy sand texture classified as Afisols based on USDA Soil Taxonomy (Oyedeji et al., 2017). Soil was air dried at room temperature (25 °C) for 2 weeks, sieved through < 2 mm and any debris was removed. Soil was then homogenized and 5 kg weighed separately into 18 polyethylene bags which represented five treatments and the control replicated three times. Waste lubricant oil (WLO) and biochars from Daniellia oliveria (BD) or Vitellaria paradoxa (BV) were then incorporated into the treatments; Control (T₀): 5 kg soil; T₁: 5 kg soil + 2% v/w WLO contamination; T₂: 5 kg soil + 2% v/w WLO contamination + 0.5% w/w BD; T₃: 5 kg soil + 2% v/w WLO contamination + 1.0% w/w BD; T₄: 5 kg soil + 2% v/w WLO contamination + 0.5% w/w BV and T₅: 5 kg soil + 2% v/w WLO contamination + 1.0% w/w BV.

The experimental set-up in the screen house was set in a randomized complete block design and watered to field capacity for two weeks. Samples of soil were collected from each polyethylene bag, air dried to constant weight and analyzed for pH, total petroleum hydrocarbon, organic carbon, total nitrogen, available phosphorus, and exchangeable K, Ca and Mg. Soil pH, organic carbon, total nitrogen and available phosphorus were determined using the procedure described for biochar. Total petroleum hydrocarbon was determined by gravimetric method as described by Villalobos et al. (2008). Exchangeable K, Ca and Mg were extracted using 1M ammonium acetate buffered to pH 7.0. Concentrations of K and Ca were determined using flame photometer (Jenway PFP7 model) while Mg was determined using atomic absorption spectrophotometer (Jenway 6305 model).

Ten cowpea seeds obtained from National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan were sown to 2 cm depth into soil treatments in the polyethylene bags. Germination (%) records were taken at commencement of germination for up to 10 days after sowing and seeds which failed to sprout after that time were considered dead. Final germination percentage (FGP), mean germination time (MGT), germination index (GI), coefficient of velocity of germination (CVG), germination rate index (GRI), first day of germination (FDG), last day of germination (LDG) and time spread of germination (TSG) were determined using the formulae outlined by Kader (2005) and mean germination rate (MR) was according to the formula by Ranal et al. (2009).

\[
FGP(\%) = \frac{Total\ \text{of}\ \text{seeds}\ \text{germinated}\ \text{in}\ \text{a}\ \text{seed}\ \text{lot}}{Total\ \text{No}\ \text{of}\ \text{seeds}\ \text{sown}} \times 100
\]

\[
MGT(d) = \frac{\sum t n_t}{\sum n_t}
\]

Where \(n\) is the number of seed(s) that germinated on day \(t\).

\[
MR(d^{-1}) = \frac{1}{MGT}
\]

\[
GI = (10 \times n_1) + (9 \times n_2) + \cdots + (1 \times n_{10})
\]

\[
CVG = \frac{100(n_1 + n_2 + \cdots + n_{10})}{(n_1 + n_2 + \cdots + n_{10})}
\]

Where \(n\) is number of seeds germinated each day, \(t\) is number of days from seeding corresponding to \(n\).

\[
GRI(\%d^{-1}) = \frac{G_1}{1} + \frac{G_2}{2} + \cdots + \frac{G_x}{x}
\]

Where \(G_1, G_2, \text{and} G_x\) are germination percentages at day 1, 2 and \(x\) respectively.
RESULTS

The chemical properties of biochars from *Daniellia oliveri* (BD) and *Vitellaria paradoxa* (BV) are presented in Table 1. BV had significantly higher (P < 0.05) total nitrogen, potassium and magnesium than BD. BD had higher calcium while pH, organic carbon, phosphorus concentrations in the biochars was not significantly different. The chemical properties of the native soil, WLO-contaminated and biochar-amended soils are presented in Table 2. Soil pH was significantly low in T₀ (control), T₁ and T₅. T₆ had the significantly highest (P < 0.05) pH and followed by T₇. Biochar amended soils (T₂ to T₅) had significantly higher OC, TN, K, Ca, Mg but lower TPH compared with T₀. T₅ had the least concentration of P but significantly higher N than T₀. BD significantly improved pH, OC and exchangeable Ca concentrations. BV significantly reduced TPH concentration in the soil but improved exchangeable Ca and Mg.

Germination characteristics of the cowpea seeds in the control, WLO-contaminated and biochar-amended soils are presented in Table 3. Final germination percentage (FGP) significantly varied and reached 100% in the control.
and treatments, except $T_1$ and $T_3$. Mean germination time (MGT) was significantly highest in $T_1$ (6.05 days) and least in $T_3$ (4.07 days). Mean germination rate or germination speed (MT) was fastest in $T_0$ (0.25 day$^{-1}$) and slowest in $T_1$ (0.17 day$^{-1}$). The germination index (GI) and coefficient of velocity of germination (CVG) were highest in $T_3$ (34.67 and 24.60) while $T_1$ had the least GI and CVG (24.33 and 16.56). Germination rate index (GRI) was also highest in $T_3$ (24.67 % day$^{-1}$) and lowest in $T_1$ (14.71 % day$^{-1}$). The first, last day, and time spread of germination (FDG, LDG and TSG) also varied significantly ($P < 0.05$). Seeds in $T_0$, $T_1$, and $T_3$ started germination earliest (i.e. on the 4th day). Seeds in $T_1$ had the longest period of germination (7.67 days). TSG was shortest in $T_0$ (1.33 day) and longest in $T_1$ (3.67 day).

DISCUSSION

The variation in the chemical properties of Daniellia-derived and Vitellaria-derived biochars was in line with earlier report by Jindo et al. (2014) that the nature or type of feedstock strongly influences the physicochemical properties of biochars. pH of Daniellia-derived and Vitellaria-derived biochars in this study exceeded the pH (8.32) reported by Gulyas et al. (2014) for wood chip (WC) but fall within the range of 7 - 9 reported by Beesley et al. (2011). Hunt et al. (2010) also asserted that the initially high (alkaline) pH of biochar is desirable when used with acidic, degraded soils. Also, the percentage carbon of biochars from the two species was higher than 9.9 % reported by Gulyas et al. (2014) for animal bone biochar (ABC). The result of total nitrogen concentrations in the two biochars were similar to that of wood chip and animal bone biochars reported by Gulyas et al. (2014), but phosphate and exchangeable cations concentrations in this study varied considerably.

The higher pH in the biochar-amended soils in this study confirms earlier report by Beesley et al. (2011) that addition of biochar, which typically have a pH of 7-9, to acidic soils will result in an increase in the soil pH. The significant reduction in TPH concentration in the biochar-amended soils confirms earlier report by Beesley et al. (2010) and Gomez-Eyles et al. (2011) that biochar amendment in soil reduces petroleum hydrocarbons contamination. In addition to pH modification, Beesley et al. (2011) also affirm the potential of biochar to increase soil OC and exchangeable cations. According to Granatstein et al. (2009), biochar represents a stable form of carbon in the soil and thus provides an intriguing potential carbon storage strategy.

The high N content in the waste lubricant oil-contaminated soils in relation to the control could be linked to input from the oil. Posthuma (1970) asserted that petroleum contains nitrogen and oxygen in low concentrations as well as metals such as lead, nickel, sodium, calcium, copper and uranium. Apart from direct nitrogen addition from the biochars, improvement in soil N in the amended soils could be linked to increased activity of beneficial microorganisms due concomitant nutrient and water retention created by the large surface area and porosity of biochars (Hunt et al., 2010). Low phosphate in WLO-contaminated soils is due to presence of hydrocarbons as affirmed by Amadi et al. (1996). Higher P levels in the soils amended with Daniellia-derived biochar is related to P content in the biochar. Cao and Harris (2010) found that biochar is rich in P, and unlike C and N, an increase in the production temperature increase P likewise Mg and Ca. High exchangeable cations in the biochar-amended soils is characteristic of the biochars from the two sources in this study. The result is consistent with Biederman and Harpole (2013) that biochar addition to soils may increase concentrations of exchangeable cations, depending on the intrinsic properties of the soil and the biochar. Nwite (2013) also reported improvement in K, Ca and cation exchange capacity in oil-contaminated soils amended with charred rice husk. Generally, chemical properties of the biochar-amended soils varied with concentration and source material of the biochar.

The reduction in the final germination percentage (FGP) of cowpea seeds in the unamended WLO-contaminated treatment corroborates the findings of Lale et al. (2014), who observed slow and low germinability of cowpea seeds in the soil contaminated with 2% waste engine oil. Udo and Fayemi (1975) concluded oil-pollution affect seed germination as seeds absorb oil in the soil and get destroyed. The high mean germination time (MGT) and low mean germination rate (MT) for seeds in the WLO-contaminated treatment indicate the inhibitory effect of oil on germination. The results of FDG and LDG in the control and the biochar-amended soils fall within the range (4 to 5 days) reported by Akinyosoye (1976) and Gbadebo and Adenuga (2012). The extended germination period of 5 to 7 days observed in the unamended WLO treatment also coincides with 6-8 days interval observed by Gbadebo and Adenuga (2012) for cowpea seedling emergence in the highest oil treatment. According to Adam and Duncan (2002), volatile components of light hydrocarbons in oil capable of penetrating plant cell wall can be phytotoxic thus delaying or decreasing seed germination. These effects of delayed and decreased germination accounted for the variation in germination indices including germination index (GI), germination rate index (GRI) and coefficient of velocity of germination (CVG) in this study. The closeness of seed germination results in the control ($T_0$) and $T_3$ (oil contaminated soil amended with 1% Vitellaria-derived biochar) showed the biochar application is effective in ameliorating the effects of waste lubricant oil contamination.

CONCLUSION

The present study showed that waste lubricant oil significantly increased soil N but decreased available P. Incorporation of Daniellia- and Vitellaria-derived biochars to the waste lubricant oil contaminated-soils significantly improved the soil pH, OC and exchangeable cations, which ultimately facilitated the germination of cowpea seeds compared to the un-amended WLO-contaminated soils. Vitellaria-derived biochar at (higher concentration) showed greater potential in ameliorating the effects of oil contamination and enhancing germination of cowpea seeds than Daniellia-derived biochar.
ACKNOWLEDGEMENT

The authors are thankful to members of staff of Seed Gene Bank Unit at National Centre for Genetic Resources and Biotechnology, Ibadan, Nigeria for assisting with certified cowpea seeds used for the study.

REFERENCES

Achuba, F. I. (2006). The effect of sublethal concentrations of crude oil on the growth and metabolism of cowpea (Vigna unguiculata) seedlings. Environmentalist 26: 17-20.

Adam, G. and Duncan, H. J. (1999). Effect of diesel fuel on growth of selected plant species. Environmental Geochemistry and Health 21: 353-357.

Adam, G. and Duncan, H. J. (2002). Influence of diesel fuel on seed germination. Environmental Pollution 120: 363-370.

Agbogidi, O. M. (2010). Response of six cultivars of cowpea (Vigna unguiculata L. Walp) to spent engine oil. African Journal of Food Science and Technology 1(6): 139-142.

Agbogidi, O. M. and Ejemeta, O. R. (2005). An assessment of the effects of crude oil pollution on soil properties, germination and growth of Gambaya albida (L.). Uniswa Research Journal of Agriculture, Science and Technology 8(2): 148-155.

Akinyosoye, V. A. (1976). Senior Tropical Agriculture. Macmillan Publishers Ltd., London and Basingstoke, Pp 199.

Amadi, A., Abbey, S. D. and Nwa, A. (1996). Chronic effects of oil spill on soil properties and micro-flora of a rainforest ecosystem in Nigeria. Water, Air and Soil Pollution 86: 1 – 11.

Amakiri, J. O. and Onofeghara, F. A. (1984). Effects of crude oil on the germination of Zea mays and Capsicum frutescens. Environmental Pollution 35: 159-167.

Atuanya, E. I. (1987). Effects of waste engine oil pollution on physical and chemical properties of soil. A case study of Delta soil in Bendel State. Nigerian Journal of Applied Sciences 5:156-176.

Beesley, L., Moreno-Jiménez, E. and Gomez-Eyles, J. L. (2010). Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. Environmental Pollution 158: 2282–2287.

Beesley, L., Moreno-Jiménez, E., Gomez-Eyles, J. L., Harris, E., Robinson, B., and Sizmur, T. (2011). A review of biochars’ potential role in the remediation, revegetation and restoration of contaminated soils. Environmental Pollution 159: 3269-3282.

Biederman, L. A. and Harpole, W. S. (2013). Biochar and its effects on plant productivity and nutrient cycling: a metaanalysis. GCB Bioenergy 5(2): 202–214. doi: 10.1111/gcbb.12037

Bona, C., de Resende, I. M., Santos, G. de O. and de Souza, L. A. (2011). Effect of soil contaminated by diesel oil on the germination of seeds and the growth of Schinus terebinthifolius Raddi (Anacardiaceae) seedlings. Brazilian Archives of Biology and Technology 54(6): 1379-1387.

Brenner, J. M. (1996.) Nitrogen total. In: D. L. Sparks (Ed.), Methods of Soil Analysis, Part 3, Chemical Methods, Soil Science Society of America, Madison, Wisconsin, pp. 1085-1121.

Cao, X. and Harris, W. (2010). Properties of dairy-manure-derived biochar pertinent to its potential use in remediation. Bioresource Technology 101: 5222-5228.

Cunningham, S. D. and Ow, D. W. (1996). Promises and prospects of root zone of crops phyto remediation. Plant Physiology 110: 715–719.

Faridullah, Nisar Z., Alam A., Irshad M. and Sabir, M. A. (2014). Distribution and evaluating phosphorus, potassium, calcium and magnesium in the fresh and composted poultry litter. Bulgarian Journal of Agricultural Science 20: 1368-1374.

Fellet, G., Marchiol, L., Delle Vedove, G. and Peressotti, A. (2011). Application of biochar on mine tailings: effects and perspectives for land reclamation. Chemosphere 83: 1262-1297.

Gascó, G., Paz-Ferreiro, J. and Méndez, A. (2012). Thermal analysis of soil amended with sewage sludge and biochar from sewage sludge pyrolysis. Journal of Thermal Analysis and Calorimetry 108: 769–775.

Gbadebo, A. M. and Adenuga, M. D. (2012). Effects of crude oil on the emergence and growth of cowpea in two contrasting soil types from Abeokuta, southwestern Nigeria. Asian Journal of Applied Sciences (2012), doi:10.3923/ajaps.2012

Gomez-Eyles, J. L., Sizmur, T., Collins, C. D. and Hodson, M.E. (2011). Effects of biochar and the earthworm Eisenia fetida on the bioavailability of polycyclic aromatic hydrocarbons and potentially toxic elements. Environmental Pollution 159: 616-622.

Granatstein, D., Collins, H., Garcia-perez, M. and Yoder, J. (2009). Use of Biochar from the Pyrolysis of Waste Organic Material as a Soil Amendment. Center for Sustaining and Natural Resources, Washington State University Ecology Publication Number 09-07-062.

Gulyas, M., Fuchs, M., Kocsis, I. and Fuleky, G. (2014). Effect of the soil treated with biochar on the rye-grass in laboratory experiment. Acta Universitatis Sapientiae (Agriculture and Environment) 6: 24-32.

Hunt, J., DuPonte, M., Sato, D. and Kawabata, A. (2010). The basics of biochar: a natural soil amendment. In Soil and Crop Management SCM-30, College of Tropical Agriculture and Human Resources (CTAHR), University of Hawaii, Manoa, pp. 1-6.

Jindo, K., Mizumoto, H., Sawada, Y., Sanchez-Monedero, M. A. and Sonoki, T. (2014). Physical and chemical characterization of biochars derived from different agricultural residues. Biogeosciences 11: 6613–6621.

Kader, M. A. (2005). A comparison of seed germination calculation formulae and the associated interpretation of resulting data. Journal & Proceedings of the Royal Society of New South Wales 138: 65–75.

Korade, D. L. and Fulekar, M. H. (2009). Effect of organic contaminants on seed germination of Loliolum multiflorum in soil. Biology and Medicine (Bio. Med.) 1: 28-34.

Lale, O. O., Ezekwe, C. and Lale, N. E. S. (2014). Effect of spent lubricating oil pollution on some chemical
parameters and the growth of cowpeas (Vigna unguiculata Walpers). Resources and Environment 4(3): 173-179.

Lehmann, J., Rillig, M. C., Thies, J., Masiello, C. A., Hockaday, W. C. and Crowley, D. (2011). Biochar effects on soil biota- A review. Soil Biol. Biochem. 43: 1812–1836.

Méndez-Natera, J. R., Roque, C., Zapata, K. and OtaholaGómez, V. (2004). Efecto de la concentración y tiempo de contaminación de un suelo por petróleo en la germinación de semillas de maíz (Zea mays L.) cv. Himcea 95. Revista UDO Agrícola 4: 66-71.

Merkl, N., Schultz-Kraft, R. and Infante, C. (2005). Phytoremediation of petroleum contaminated soils in the tropics assessment of tropical grasses and legumes for enhancing oil degradation. Water, Air and Soil Pollution 165: 195-209.

Nwite, J. N. (2013). Evaluation of The Productivity of A Spent Automobile Oil-Contaminated Soil Amended With Organic Wastes In Abakaliki, South Eastern Nigeria. Ph.D. Thesis. University of Nigeria, Nsukka, Nigeria, Pp. 132.

Odjegba, V. J. and Sadiq, A. O. (2002). Effects of spent engine oil on the growth parameters, chlorophyll and protein levels of Amaranthus hybridus L. The Environmentalist 22: 23-28.

Olsen, S. R. and Sommers, L. E. (1982). Determination of available phosphorus. In: A. L. Page, R. H. Miller and D. R. Keeney (Eds.), Method of Soil Analysis vol. 2, American Society of Agronomy, Madison, Wisconsin, Pp. 403.

Paz-Ferreiro, J., Lu, H., Fu, S., Méndez, A. and Gascó, G. (2014). Use of phytoremediation and biochar to remediate heavy metal polluted soils: A review. Solid Earth 5: 65–75.

Posthuma, J. (1970). The composition of petroleum. Rapports et Procès-Verbaux des Réunions 171: 7-16.

Qayyum, M. F., Stefens, D., Reisenauer, H. P. and Schubert, S. (2014). Bio-chars influence differential distribution and chemical composition of soil organic matter. Plant, Soil and Environment 60: 337–343.

Ranal, M. A., De Santana, D. G., Ferreira, W. R. and Mendes-Rodrigues, C. (2009). Calculating germination measurements and organizing spreadsheets. Revista Brasileira de Botanica 32(4): 849-855.

Schwab, A. P. and Banks, M. K. (1999). Phytoremediation of petroleum contaminated soils. In: D. C. Andriano, J. M. Bollag, W. T. Frankenberger Jr. and R. C. Sims (Eds.), Bioremediation of Contaminated Soils, American Society of Agronomy, Crop Science, Society of America, Soil Science Society of America, Madison, Pp. 783-795.

Sharifi, M., Sadeghi, Y. and Akbarpour, M. (2007). Germination and growth of six plant species on contaminated soil with spent oil. International Journal of Environmental Science and Technology 4: 463-470.

Shukry, W. M., Al-Hawas, G. H. S., Al-Moaikal, R. M. S. and El-Bendary, M. A. (2013). Effect of petroleum crude oil on mineral nutrient elements, soil properties and bacterial biomass of the rhizosphere of jojoba. British Journal of Environment and Climate Change 3(1): 103-118.

Smith, M. J., Flowers, T. H., Duncan, H. J. and Alder, J. (2006). Effects of polycyclic aromatic hydrocarbons on germination and subsequent growth of grasses and legumes in freshly contaminated soil and soil with aged PAHs residues. Environmental Pollution 141: 519-525.

Udo, E. J. and Fayemi, A. A. (1975). The effect of oil pollution of soil on germination, growth and nutrient uptake of corn. Journal of Environmental Quality 4:537-540.

Udo, E. J. and Oputa, C. O. (1984) Some Studies on the effect of crude oil pollution of soil on plant growth. Journal of Applied Biological Chemistry 2: 215-218.

Udom, B. E., Ano, A. O. and Chukwu, W. (2012). Contaminant limit (e/p index) of heavy metals in spent oil contaminated soil bioremediated with legume plants and nutrients. Journal of Soil Science 22:144-152.

Vavrek, M. C. and Campbell, W. J. (2002). Contribution of seed banks to freshwater wetland vegetation recovery. Louisiana Applied and Educational Oil Spill Research and Development Program, OSRADP. Technical Report Series, 12 pp.

Villalobos, M., Avila-Forcada, A. P. and Gutierrez-Ruiz, M. E. (2008). An improved gravimetric method to determine total petroleum hydrocarbons in contaminated soils. Water, Air and Soil Pollution 194: 151-161.

Walkley, A. and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Science 37: 29-38.

Wang, S., Zhao, X., Xing, G. and Yang, L. (2013). Large-scale biochar production from crop residue: a new idea and a biogas-energy pyrolysis system. BioResources 8(1): 8-11.

Yang, X.-B., Ying, G.-G., Peng, P.-A., Wang, Li., Zhao, J.-L., Zhang, L.-J., Yuan, P., He, H.-P. (2010). Influence of biochars on plant uptake and dissipation of two pesticides in an agricultural soil. Journal of Agricultural Food and Chemistry 58: 7915-7921.

Yu, X. Y., Ying, G. G. and Kookana, R. S. (2006). Sorption and desorption behaviors of diuron in soils amended with charcoal. Journal of Agricultural and Food Chemistry 54: 8545-8550.

Yu, X. Y., Ying, G.G. and Kookana, R. S. (2009). Reduced plant uptake of pesticides with biochar additions to soil. Chemosphere 76: 665-671.

Zhang, H., Lin, K., Wang, H. and Gan, J. (2010). The effect of Pinus radiata derived biochars on soil sorption and desorption of phenanthrene. Environmental Pollution 158: 2821–2825.