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Review

Importance of soil physical characteristics for petroleum hydrocarbons phytoremediation: A review

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Petroleum and petrochemical hydrocarbons for some places are serious sources of environmental pollutants. To remediate these contaminants, phytoremediation, a relatively low cost and an environmental friendly technique is recommended more widely, now more than ever. Successful and effective applying of hydrocarbons phytoremediation depends mainly on the soil and plant types and conditions and microbial activities and the interactions between these three factors. Although for the last several decades, various plant and organism's species for the phytoremediation processes have been extensively studied, evaluating and characterizing soil properties, as an important objective for sustainable remediation and land use management, which had negligible considerations. An ideal soil for phytoremediation should have proper physical, chemical and biological characteristics to let the plant grow well and produce biomass as high as possible. It also should provide favorable conditions for microbial activities to perform efficient remediation. Soil physical characteristics such as texture, structure, water status and aeration are important factors affecting the microbial activities and consequently the degree of remediation potential. A better understanding of soil physical properties in conjunction with proper soil-plant-microbe management could be exploited to enhance the remediation of hydrocarbon contaminated soils and thus sustainable healthy environment.

Key words: Phytoremediation, petroleum, hydrocarbon.

INTRODUCTION

In the current industrial society, using petroleum as a primary source of energy and for petrochemical byproducts is inevitable (Bierkens and Geerts, 2014), but for some specific places these activities pose the major sources of soil and water pollution as well (Hentati et al., 2013). According to Macci et al. (2013), industrialization during the past decades caused an ever-increasing reliance on petrochemicals, and as a consequence, many sites have been significantly contaminated with petroleum and the petroleum-byproducts (Jesus et al., 2015 and Gennadiev et al., 2015). This is especially more serious around the petroleum and petrochemical complexes and refineries in the countries producing these materials and generally the overall industrialized regions.

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According to the EPA (US Environmental Protection Agency) the very hazardous chemicals like benzene, toluene, ethylbenzene, xylenes, and naphthalene are included in the petroleum hydrocarbons (Lehmann et al., 2006, Bojes and Pope 2007, Gao and Collins, 2009, Cook et al., 2010, Boonsaner et al., 2011, Fester et al., 2014, Germaine et al., 2015). These pollutants can affect soil physical characteristics like soil texture and structural status, compaction, saturated hydraulic conductivity, and penetration resistance (Hreniuc et al., 2015). When released on the surface soil, petroleum hydrocarbons, with a specific physico-chemical characteristics (Zahed et al., 2010) pushes soil toward a condition undesirable for proper and sustainable growth of plant and rhizosphere organisms activity (Gaskin and Bentham, 2010; Masakorala et al., 2014). Sources of spreading hydrocarbons also include storage tanks leakage, which only in 1994 was estimated to be around 250,000 numbers in the USA (Buswell, 1994). This means that presence of these contaminants in soil significantly reduce the quality of soil and thus minimize the germinating, growth and health of plants (Tang et al., 2010a). Therefore, remediation and removing of these materials from soil is necessary for the sustainable environmental health (Kang, 2014; Nichols et al., 2014). The petroleum contaminants are mixtures of solid, liquid and gaseous of hydrocarbon molecules with linear or polyaromatic structures (Moubasher et al., 2015); so not all compounds should be treated similarly and remediated by identical mechanism.

The source and degree of processing of the petroleum hydrocarbon adds an additional layer of complexity as, hydrocarbons may be in the form of crude oil or refined products such as gasoline, diesel or plastic byproducts (Kaimi et al., 2007; Barnes et al., 2009). Aging of the compounds in soil is another factor affecting the remediation phenomena (Wang et al., 2014). Phyto-remediation, make the use of plants to remediate contaminated soil, water or air and as an environmentally safe technique which is more than ever used in treatment or removing of pollutants from the contaminated sites (Tang et al., 2010b; Rascio and Navari-Izzo, 2011; Lotfinasabasl et al., 2013). Comparing to the destructive and expensive traditional methods (washing, excavating or thermalizing), this is a relatively low cost alternative, recently used for the remediation of a variety of environments (soil and water), contaminated with heavy metals and/or petroleum hydrocarbons (Semple et al., 2003; Ahn et al., 2008; Marek et al., 2009; Falciglia et al., 2011). However, using the phytoremediation technique maybe limited to a certain soil depth (up to the root zone area) and to a relatively low contaminants concentration. Phytoremediation is a collaborating soil, plant and organisms technique, in which plants, basically through the root systems clean, remediate or detoxify the polluted sites (Kamath et al., 2004; Isitekhale et al., 2013; Abhilash et al., 2014). The basic processes of phytoremediation include: transforming, stabilizing, assimilating, metabolizing or detoxifying of the hydrocarbon molecules.

Almost all of these procedures are depended on the interaction between the soil, plant and organisms (Zhang et al., 2010). In this regard, soil is the basic support for plant growth and a necessary medium for the organism's activity in almost all ecosystems; therefore a successful phytoremediation management tentatively relies on the power of this collaboration. According to Padmavathiamma et al. (2014) for the phytoremediation technique to be successful, answering the following questions are crucial; if the contaminants allow the species to be germinated or transplanted, if the species are able to inoculate with the presenting micro organisms and if the use of local versus exotic plants and microorganisms is possible. An important factor in this regard is that, phytoremediation efficiency is absolutely affected by the concentration of petroleum contaminants (Peng et al., 2009).

After delineating and expressing the type and extent of contaminated soil and also finding out the methods to quantify the petroleum substances (Gan et al., 2009; Liu et al., 2011; Zhang et al., 2012; Abdullah et al., 2014; Pinedo et al., 2014; Potashev et al., 2014; Zhang et al., 2014; Wolejko et al., 2016), the subjected soil should be characterized as the first step in planning remediation strategies (Mao et al., 2009). This step includes testing and analyzing soil physical, chemical and biological characteristics. These analyses bring details of the degree of succession for the techniques such as microbial-based, bio-stimulation (Haslmayr et al., 2014) and bio-augmentation or phytoremediation in the processes of hydrocarbon degradation (Ayotamuno et al., 2006; Towell et al., 2011).

It is basically the soil conditions which manage plant-microbe interactions (Alrumman et al., 2015), therefore an ideal soil for phytoremediation should have proper characteristics in order to, let the plant grow well and produce biomass as high as possible (Khan et al., 2013; Phillips et al., 2012). Soil physical properties such as texture, structure, aeration and water status are among the factors affecting root-organism activity and performance. It is also the root exudates that cause the soil to become firm resulting in, movement of oxygen into deeper soil layer, higher root growth, more micro-organisms' activity and thus more hydrocarbons degrading (Técher et al., 2011). Soil characteristics and plant-microbe interaction, significantly affect soil nutritional status, the quality and quantity of root exudates and consequently on bioavailability-remediation of petroleum hydrocarbons and heavy metals at the rhizosphere area (Técher et al., 2012). During the last three decades many researchers reported the importance of, different plant and organism species during the phytoremediation processes, but very little is mentioned about the soil part in this regard.

However, the efficiency of phytoremediation, degrading activities and performance of this technology greatly depend on factors like soil type, water status, nutrient bioavailability, soil temperature and aeration condition, salinity, sodicity and pH. Although, not well documented, evaluating and characterizing soil properties during phytoremediation processes can be a valuable help for decision making and finding possible use of different remediation techniques. In this review the role of a number of soils physical characteristics are being explained during the phytoremediation processes of petroleum hydrocarbon.

Soil texture (particle size and distribution), structure (pore size and tortuosity), consistency, bulk density (compaction), organic matter and moisture content, temperature status, and salt and nutrient content are some of the most important physical characteristics affecting root growth and development. Proper soil conditions allow roots to have the proper growth and thus having higher phytoremediation efficiency. For roots, the following morphological parameters are important: root architecture, structure, tensile strength, tortuosity, number, diameter, conditions (live or dead) and root hairs (Wang et al., 2013; Loades et al., 2013) which almost all, depends on soil physical (textural and structural) characteristics. In the following sections some of the important soil physical characteristics involved in the processes of phytoremediation of petroleum hydrocarbons are, being evaluated.

HYDROCARBONS (HC) AND SOIL QUALITY

Several studies have highlighted factors such as soil organic matter content, temperature, pH, salinity, nutrient availability (particularly nitrogen and phosphorus), soil moisture content, oxygen availability and redox potential, influencing the bioremediation and phytoremediation processes (Chaillan et al., 2006, Lone et al., 2008, Wang et al., 2012 and Waqas et al., 2014). In soil, plant seeds should be able to absorb water, to germinate at the first place then anchor, stabilize and support the plant afterwards. The microbes should also be able to biologically function in soil, in order to function as the remediation tool, but in this regard unfavorable soil conditions have diverse effects (Afzal et al., 2011). The mentioned parameters are examples of soil quality indices. Soil quality is an important factor for sustaining plant and animal productivity, maintaining/ enhancing water and air quality, and supports the life of people on the earth, now and in the future. Traditional strategies for improving soil quality includes increasing physical properties like aggregation or optimizing particle size distribution (Herrick et al. 2001), lowering salinity (Lawton, 2015; Kalliola et al., 2016), adjusting extremely low or high pH to more neutral values, increasing plant coverage (Laird and Chang, 2013) and enhancing microbial community activity in the rhizosphere (Lamers et al., 2012; Wang et al., 2013).

However, the quality of soil is continuously subjected to all kinds of environmental stress or produced by human activities such as production of petroleum hydrocarbons. With the growing societal and industrial demands this kinds of pollution is occurring through transportation, accidental spills and during petroleum refining operations. As reported by Pathak et al. (2011), petroleum hydrocarbon contamination is able to increase toxicity and thus lowering soil quality. According to Pathak et al. (2011) and Onojake and Osuji (2012) soil physical and chemical quality such as moisture status, pH, EC, and water holding capacity is significantly reduced by petroleum hydrocarbon contaminations. On the other hand attributes like soil textural, structural and water and air characteristics are important factors to accelerate or reduce the degradation of soil pollutants. In this respect, Pathak et al. (2011) stated that, the particle and pore size distribution by affecting soil aeration, bulk density, hydrocarbon movements (both vertical and lateral) and adsorbing/desorbing contaminants, significantly enhance or lower the degradation of pollutants. When contaminants like petroleum hydrocarbons are present on the soil surface, both biodegradative and non-biodegradative processes happen in soil. The non-biodegradative processes include draining due to irrigation, evaporation/volatilization, direct plant uptake and adsorption by soil particles or organic matter. Almost all of the non-biodegradative processes are in association with soil physical characteristics. Results in most of the studies show that, TPH loss through direct plant uptake is negligible because mixtures of petroleum hydrocarbons similar to diesel oil could not be taken up by the plant (Schwab and Banks, 1994; Reilley et al., 1996).

In this review the attempt is to relate the effects of hydrocarbon contaminations on soil physical characteristics as the major soil quality attributes.

PHYTOREMEDIATION OF HC AND SOIL TEXTURE

Relative quantities of sand, silt and clay form a soil textural class. Texture is a basic soil property which influences other characteristics such as water holding capacity, root growth and development and nutrient dynamics in soil. The amounts and sizes of different particles should, provide proper balance between the macro and micro pores for easy air and water movement, in soil and holding water as well. These physical properties have direct effects on the dynamic and fates of any elements in soil (Scherr et al., 2007; Abdel-Moghny, 2012). Clayey soils are more plastic and sticky and have more swell and shrinkage activity and the presence of petroleum hydrocarbon in it results in, more stickiness, binding and clogging. While sandy soils have less plastic and stickiness properties, so the mobilization of the contaminants would be easier in these course textured soils (Abdel-Moghny, 2012). Generally, coarser particles (sand) when mix with the fine clays and silt, build pore spaces with different shapes and sizes, then provide various routes and fates for the contaminants like petroleum hydrocarbons. Lee et al. (2002) showed that sand is able to recover about 73% of toluene and 84% of TCB when tested in a batch experiment. They also reported that, sandy soils are more effective for surfactant remediation than clay soils because the clay surface adsorption reduce surfactant effectiveness. Not only the diversity and abundance of the clay, minerals is an important factor in the remediation processes, but sometimes the fractions of fine particles in one specific texture control the procedure (Carvalho et al., 2015). Falciglia et al. (2011) investigated soil textural behavior (coarse, medium, fine sand, silt and clay size aggregate fractions) involved with artificially polluted diesel fuel, and thermally treated at different temperatures. They concluded that desorption efficiency is influenced by soil texture such that fine sandy soil showed the highest desorption of the contaminant, and a temperature of 175°C is good enough to reach low contaminant residual concentration of almost100 mgkg^{-1} for all size fractions. For the clay, the highest desorption happened at temperature around 250°C (Falciglia et al., 2011).

In another study, limestone and granite with specific clay minerals showed higher duration for achieving the target remediation efficiency but schist with the highest fine fraction and no clay minerals, resulted in the lowest time necessary for remediation (Carvalho et al., 2015). Yanai et al. (2006) showed that along with coarser textural particles, low pH (between 5 and 6) and high concentrations, resulted in more Cd uptake by *Thalaspi caerulescens* plant. Soil amendments or conditioners like biochar (Sarkar et al., 2005; Qin et al., 2013) or zeolite (Wen et al., 2016) are also able to modify soil textural and structural and thus diverting the mobility of some heavy metal ions (Zn, Pb, Cu and Cd). This could be due to the influence of soil amendments on plant rhizosphere and thus on PAH bioavailability (Gana et al., 2009; Marchal et al., 2014).

Wang et al. (2012) and Waqas et al. (2014) also reported the effects of amendments like compost and sewage sledges and biochar on remediation of some PAHs. Soil texture, by controlling bioavailability of the plant nutrients and the contaminants would change the phytoremediation result (Figueiredo et al., 2016). This is because clay can bind molecules stronger than silt or sand therefore, the bioavailability of contaminants is lower in soils with higher clay contents (Abdel-Moghny, 2012). Sandy soils commonly have higher PAH mineralization comparing to silt and especially to the clay particles which could be due to the greater bioavailability of the contaminants in the sandy soils (Carmichael and Pfaender, 1997). Edwards et al. (1982) showed that soybean bioavailability and uptake of ^{14}C-anthracene from nutrient solution is higher than from soil, which could be due to more adhering of the PAHs to soil particle than to the water molecules. This also might be due to the chemical hydrophobicity of some contaminant substances in soil (Dettenmaier et al., 2009). According to Sterling et al. (2004a,b) in a modeling approach of simulating the changes in particle size distribution and density due to aggregation, clay and crude oil were categorized as cohesive particles and colloidal silica was classified as non-cohesive. To show the interaction between soil particle size, contamination and the functionality of microorganisms, Amellal et al. (2001) pointed that degrading bacteria are more active in the silt and clay particles in the uncontaminated soils, but when contaminated, the sandy texture soils showed higher microorganism's populations and activity.

In another study Huesemann et al. (2004) also showed that soils with low percentages of fine silt and clay demonstrated higher degradation rates of hydrocarbons. This could be due to the aeration porosity which in turn depends on soil texture. Sandy soils have a higher percentage of macro and the clayey soils produces more of the micro pores, so the clay soils are more susceptible to water logging which can adversely affect root respiration and microbial activity, therefore in the water lodging situation degradation of hydrocarbons would dramatically reduce. Regarding the phytoremediation of petroleum hydrocarbon, it can be concluded that, because the contaminants have weaker binding to the particles and both plant roots and organisms are more active in the coarser soil textures, there appear to be more performances in the coarse comparing to the finer textural classes.

PHYTOREMEDIATION OF HC AND SOIL STRUCTURE

Soil structure is "how the particles joint or bind together to form a larger piece of soil named lumps or aggregates". Soil structure as a dynamic property is subjected to change via various soil management practices such as tillage, crop rotation, irrigation, drainage and also to contaminations like petroleum hydrocarbons. Pores between the soil particles are occupied by air and/or water which control the functions such as seeds emergence and plant growth and number and kinds of organisms. Roots are only able to move through the spaces between the particles or aggregates, so the soil should have an aggregating structure such that the roots of the seedling which can easily penetrate into it. Spaces between the aggregates are macro while those between the individual particles of the aggregates are micro pores. Therefore, soil physical properties should not be any containment to the seed emergence and root growth processes, but the presence of contaminants like petroleum hydrocarbons in soil would disturb this habitat. In an experiment referring to the interaction between soil aggregation and hydrocarbon contamination Amellal et al. (2001) indicated that, more PAHs were found in the smaller size fractions (clay < 2 µm and fine silt 2 to 20 µm) compared to the sand and coarse silt. This accumulation and binding process is driven predominantly by the organic carbon content of the fractions (Tan et al., 2007; Guimara et al., 2013; Razafimbelo et al., 2013). The degrading microbes of PAHs were also distributed un-evenly through out the soil particles with different sizes (Razafimbelo et al., 2013). The collaboration of organic matter in soil for building aggregates in several land use managements had, variety of influences on the fate of PAHs, reported by Xiao et al. (2014). They reported that total PAHs were strongly bound to soil organic matter and since OM is an important binding agent for aggregation, the larger and more stable aggregates (naturally with more OM) contain more PAHs too. One of the important and promising ways to positively alter soil aggregation fractions and thus improving hydrocarbon degradation is the addition of binding agents to the soil. Commonly these agents could be very simple plant residues (different organic materials) with low density and when incorporated with soil it lowers the bulk density and increase porosity and oxygen diffusion and further help building water-stable soil aggregates. These materials include vermiculite (inorganically), and saw dust, wheat bran, hay and other grass residues organically enhance jointing soil particle together and consequently increase aeration, microbial activity and thus hydrocarbon degradation (Razafimbelo et al., 2013). In respect to soil aggregation and remediation processes some other complexities like root growth and functions, soil water status and chemical properties (i.e. salinity) should be considered. Roots while growing, release organic material into soil, stabilizing aggregates (Gurska et al., 2009 and Tejeda et al., 2013) but salinity by dispersing the aggregates that cause soil structural deterioration (Rengasamy and Olsson, 1991). Soil heterogeneity as an index of texture and structural status that alter mycorrhizal colonization and pollutant distribution in soil so, these can substantially change the plant response and functionality for phytoremediation (Langer et al., 2010; Liu et al. 2016). According to Liu et al. (2016) sedimentary heterogeneity has a significant effect on hydrocarbon accumulation, which in turn might have similar influences on release and remediation of these compounds. Soil aggregation regulates soil structural stability, root penetration and water and air infiltration which all are physical properties and are important for soil erosion and permeability (Bengough et al., 2006) and through this phenomenon the fate of hydrocarbons in soils may alter.

Compaction as a deteriorating soil physical and structural status is a process by which the bulk density of soil increase, pore space decrease, water and air movement and biological activities restricted. The basic phytoremediation processes such as removing, degrading, transforming, or stabilizing of the contaminants depend on the soil dynamic properties like aeration porosity which is known as an important index for soil structural status. Therefore, if compaction occurs some processes in contaminated soil like the rate and quantity of phytoremediation of petroleum hydrocarbons may be reduced. Water and air content which strongly are related to the soil texture and structural status, both known as the key factors involved in polyaromatic hydrocarbons (PAH) bioremediation. A well structured and aggregated soil enhances both movement and fate of the petroleum contaminants (Sterling et al., 2004). According to Pathak et al. (2011) the vertical movement of the petroleum contaminants is changed not only because of the alteration in aggregate density, but may be due to the reduced sediment aggregate porosity.

Lee et al. (2002) also mentioned that these effects might be because of the interaction between the petroleum substances and the soil particles and also due to the buoyancy effects of the contaminants in the substance-clay aggregates. Compact soil layers limit root growth and also adversely affect properties related to water and air movement in soil and around plant roots. A good structured soil provide proper condition for plant root growth and mutually increasing root activity which results in a good soil structure, with a dynamic situation for water, air and nutrients in soil. Petroleum hydrocarbons in a structurally hard and naturally weathered soil, according to Gerhardt et al. (2009), commonly causes the contaminants not to be readily bioavailable. This could be due to the hydrophobic characteristics of the petroleum components which retard mass transfer of air, water, and contaminants from particles to microorganisms in soil. The consequence results will be limiting the rate of uptake and metabolism of contaminants by microorganisms (Das and Chandran, 2011). The rooting depth and the mechanism by which, nutrients reach near the root surfaces (rhizosphere) are some limiting factors affecting the petroleum contaminants remediation in soil (Loades et al., 2013). Adversely, in a well structured soil, when plant roots grow well, root penetration ease inserting air and also exerting exudates and substances into the soil, thus physical structure improve and microbial populations and activities would be enhanced and so the remediation of the petroleum contaminants. Therefore, a more enhanced plant root growth provided by proper soil physical properties (Li et al., 2002 and Loades et al., 2013) and nutritional status (Lamers et al., 2012), sufficient moisture content (Quyum et al., 2002) and good oxygen transport to lower depths in the soil (Neira et al., 2015), stimulate petroleum-degrading microorganisms (Jing et al., 2007), and could then significantly accelerate phytoremediation of soils contaminated with petroleum hydrocarbons (Tang et al., 2010a).

According to Bharti et al. (2014), lack of soil structure, low water supply and nutrient deficiency are generally intensify metal toxicity and so, decline plant growth in the contaminated soils.

PHYTOREMEDIATION OF HC AND SOIL AIR STATUS

Aeration porosity is the pore spaces in soil filled with air of relatively similar content to the atmosphere, which the oxygen is necessary for microbe and plants to respire. In this process oxygen is taken up and carbon dioxide release and almost all physiological activities, especially root elongation is dependent to the aeration. Oxygen is also require for processes like aerobic respiration or aerobic biodegradation which is the breakdown of contaminant molecules via microorganisms.

Aerobic bacteria utilize oxygen providing electron acceptor for, partitioning organic matters into smaller compounds. In this process carbon dioxide and water is produced. Habe and Omori (2003) has comprehensively reviewed the processes of breakdown and metabolism of soil-PAH in aerobic bacteria. Albergaria et al., 2008 reported that airflow rate directly affect the mass transfer and vapor extraction of contaminants such as benzene, toluene, ethylbenzene, xylene, trichloroethylene and perchloroethylene, during the remediation process. They concluded that for the dry sandy soils (if clay and natural organic matter content can be neglected) at the equilibrium between the pollutants and the different phases, the higher airflow rate exhibited the fastest remediation (Albergaria et al., 2008, 2010). Adversely, when there are lacks of, O_2 in soil metabolic processes in plants disturb, and accumulation of toxic substances, low nutrients uptakes occur. Aeration generally can also control soil temperature, regulate soil moisture, improve drainage, stimulate microbial activity and improve overall soil tilth. Many of the plant–bacteria interaction are dependent upon soil aeration porosity (Tang et al., 2010a). In Soil contaminant bioavailability, the composition of root exudates, and nutrient levels are all directly depend on aeration porosity (Carvalho et al., 2015). These processes would be inversely affected by entering and presenting hydrocarbons into soil, but not in all soils and situations.

Therefore, there is no unique solution for decreasing/ increasing degradation or improving soil productivity because soil conditions vary between contaminated points. In one study Caravaca and Roldan (2003) showed that adding of hydrocarbon contamination to soil improved porosity by more than 15 times when compared to the control soil. This happened in the contaminated sites because more cracks in 100 to 200μm size range of soil, were produced and thus, over time lead to improve soil quality and increased microbial activity. In another experiment, Kaimi et al. (2007), by cultivating twelve plant species measured the changes in total petroleum hydrocarbon concentration, soil dehydrogenase activity and the number of aerobic bacteria and concluded that TPH concentration was more dependent to the soil dehydrogenase activity than to the aerobic bacterial number. Several experiments (Metay et al., 2007; Razafimbelo et al., 2013) showed that crushing soil aggregates would enhance respiration (higher CO_2), which results in additional carbon mineralization as SOC pool, physically protected in soil aggregation. In cases when oxygen is absent or limited, biodegradation can occur anaerobically. Contrary to aerobic biodegradation, anaerobic microorganisms use other available substances such as nitrate, sulfate, iron and manganese as their electron acceptors to break down organic compounds into smaller constituents, often producing carbon dioxide and methane as the final products.

Alternatively some anaerobic microorganisms can break down organic contaminants by fermentation whereby in this case, the organic contaminants act as the electron acceptors. At the situations like accidental oil spills or water submerged soil in paddy field, swamps water logging happen, soil aggregates either crash or clogged, then due to high concentration of contaminants and lack of oxygen, anaerobic biodegradation is inevitable. Due to a low cost and small requiring area, anaerobic biodegradation is being to replace aerobic biodegradation. In an experiment Carvalho et al. (2015) reported higher (≥99.3%) remediation rates in bioventing technique (comparing to no ventilation - bioventing), confirming the importance role of oxygen on remediation. This effect was more pronounced for granite (comparing to limestone and schist) with biggest difference in remediation time, when compared to techniques of no ventilation (Carvalho et al., 2015). Furthermore, anaerobic bioremediation can be used for deep soil layers since the process does not require oxygen.

PHYTOREMEDIATION OF HC AND SOIL MOISTURE STATUS

Soil moisture content is another important characteristic when phytoremediation of petroleum products is considered. Soil moisture status can alter hydrocarbon degradation through several direct and indirect mechanisms. Soil is a reservoir of water and becoming the main supplier of the essential water for plant growth. Soil water status is important because of its significant role in natural processes and phenomenon such as evapotranspiration, infiltration and drainage of water, diffusion of gases, soil temperature status, and movement of salts and nutrients.

In particular, Fernandez and Quigley (1985) for example showed that soil hydraulic characteristics can alter PAH adsorption sites, such that when the soil is too wet the adsorption is driven by soil organic matter content, while in the dry situations clay content has the major role to adsorb the substances (Chiou and Shoup, 1985). With the presence of hydrocarbons in soil, generally, the limitations will be poor moisture-holding capacity (due to hydrophobicity), low permeability (due to clogging) and nutrient deficiencies (because of adsorption and toxicity). In some cases when petroleum hydrocarbon in soil results in enhancing soil hydrophobicity, water repellency and in turn infiltration and depleting water from the root zone would occur. According to Onwurah et al. (2007) contamination of soil by total petroleum hydrocarbons and its components limit soil fertility status and consequently its productivity. This basically happen via the effect of phenomenon like, water repellency which is an important phenomenon in this regard. According to Quyum et al. (2002) the mechanism of increasing hydrophobicity is, through declining soil wettability which brings discontinuities in the hydrophobic coating, whereas the existence of hydrophilic surfaces of soil particles enhance the wettability. Adversely, dilution of hydrophobic substances showed a pronounce reduction in soil water repellency (Quyum, 2000)). As reported by Adams et al. (2008), increasing water repellency in petroleum contaminated soil caused a decrease in the soil field capacity.

Several other researcher have mentioned high water repellency in soils confronted with petroleum hydrocarbons (Edenborn and Zenone 2007; Sublette et al., 2010; Nieber et al., 2011). They mentioned that the reduction in the electrostatic interaction between soil particles and water enhanced by a thin film of low-polarity of the compounds (i.e., hydrocarbons), around the polar surfaces of the soil organic matter (SOM) and clays, could be the reason (Adams et al., 2008a and 2008b). When dry, a film of petroleum hydrocarbon covers soil particles, bind them together and on the surface, it form a crust (Marı´n-Garcı et al., 2016). Large hydrocarbon molecules at the soil surface persist and glue the soil particles to form crust. The smaller sized molecules penetrate and move to the lower soil layers, block soil pores and stop air movement resulting in inhibition of biodegradation processes. This also leads to inhibition of roots to absorb water for retrieving sap and supporting plant metabolism, thus phytoremediation would be decreased or completely stop.

According to Ying et al. (2013) dumping of raw petroleum substances into the marsh soils is able to alkalinize the soil, reduces its fertility and deteriorate soil physical properties. In this case, phytoremediation has the potential to simultaneously restore and remediate the petroleum hydrocarbon-contaminated to these wetland soils Ying et al. (2013). In most cases petroleum contaminants are rich in salts too, which after the aging of organic substances; the salt by itself will have more deterioration influence on phytoremediation. For example Thavamani et al. (2015) showed that, the poor plant growth and earthworm mortality in their study was due to an increase in salinity (calcium sulfate) which results from high surface evaporation and not residual soil TPHs.

PHYTOREMEDIATION OF HC AND SOIL TEMPERATURE

Some of the soil physical, chemical and biological properties like acidity and pH, soil moisture content and number of organisms directly influence degradation of the hydrocarbons. But sometimes enhancing or prohibiting plant and organism's functionality, in soil would indirectly alter degradation procedures.

In this regard Njoku et al. (2009) reported that grown soybean in petroleum hydrocarbons contaminated soil can alter soil physico-chemical properties and as a consequence, degradation is enhanced. The plant root exudates by counteracting toxicity of the substances which would also provide proper conditions for a better plant growth (Hechmi et al., 2013). So, any action such as adding soil amendments or conditioners to petroleum contaminated soil could enhance and increase the rate and quality of remediation efficacy of the plants like soybean or maize (Njoku et al., 2008). Chaıˆneau et al. (2005) indicated that soil nutrient concentration for plant or microbial usage is another important parameter for degradation of contaminants like petroleum oil in soil. Temperature and moisture are the two most important factor controlling biological processes for nutrient movement and availability in soil (Sylvia, 2005). Thermal characteristics of soil have both direct and indirect influences on degradation of materials like petroleum hydrocarbons. Many different soil physical characteristics such as moisture, colour, slope of the land, vegetative cover and general soil tilth, control soil temperature. Higher soil temperature affects phenomenon such as viscosity and movement of the substances and thus enhances its chemico-physical and biological processes like volatilization. Indirectly, temperature can enhance micro-organisms and plant root growth and therefore is able to enhance degradation of the contaminants (Socolowski et al., 2010). Temperature which ranges for the growth and activity of almost all of the crops and organisms in soil is commonly restricted at the temperature lower than about 9°C and higher than 50°C. This effect is very much profound on seed germination, root and shoot growth, nutrient uptake and thus on crop growth (Socolowski et al., 2010). Generally the seeds are germinating above or below a certain range of temperature but this range may not be similar for the micro-organisms. These creatures functions well in the soil around 27 to 32°C.

PHYTOREMEDIATION OF HC AND SOIL ORGANIC MATTER

Soil organic matter (SOM) is a multi-functioning substance and an important element to regulate soil physico-chemical and biological properties. When soil is contaminated with any hazardous substance like petroleum hydrocarbon, the presence of SOM can altered the fate and dynamics of these contaminants. For example the behavior of soil microorganisms is an important factor for degrading SOM and the substances is related to any kind of stressor agents such as hydrocarbons in soil (Cruz-Hernandez et al., 2013; Oliveira et al., 2015).

According to Marinescu et al. (2010) soil organic matter adsorb petroleum contaminants and through this process reduce its mobility and forming non-extractable bound residues, harden the biocidal activity and thus, decreasing bioavailability of the components would happen. On the other hand plants exude soluble organic matter into soil then, in conjunction with organic matter, potentially increase the adsorption of the above mentioned contaminant (Arora et al., 2010; Cook and Hesterberg, 2013). Although, Fester et al. (2014) mentioned that microbes may adapt to prevailing conditions in contaminated soil, according to Pandey and Singh (2004) and Adesodun et al. (2005), physico-chemical properties of soils usually affect the organism's activities especially the metabolite functioning of soil microorganisms. Several reports have shown the influences of petroleum hydrocarbons on soil biological or physicochemical characteristics (Li et al., 2007; Chakraborty et al., 2012) may result in limited bioavailability for microorganisms. For assisting of the organic matter decomposition, presence of petroleum hydrocarbons in soil may have both positive and negative influences.

Sometimes, the hydrocarbons in soil stimulate the activity of organisms by providing their required food (carbon), so in this case degradation is being faster (Siddiqui and Adams, 2002). According to Masakorala (2014) almost all of the acclimated bacterial populations are active and vigorous in most contaminated soils, and especially at the vicinity of soil-root rhizosphere. As mentioned by Kaimi et al. (2006), Jing et al. (2007) and Kaimi et al. (2007), rhizosphere (important interface of soil and plant), is an important area which plays a vital role in phytoremediation of contaminated soils (Maletić et al. 2013). At the rhizosphere area microorganisms positively affect heavy metal mobility and thus to the availability of the ions for the plants by different mechanisms. These mechanisms include chelating agents, acidification, phosphate solubilization and redox changes, which all have potential to enhance phyto-remediation processes and efficiency. But, if a large amount with high toxic substances concentration of the hydrocarbons entered into the soil, it causes mortality of the microbes, so that the decomposition of the contaminants would be seized (Siddiqui and Adams, 2002; Khan et al., 2013; Fester et al., 2014).

However, the petroleum compounds may also interact with some other ambient abiotic factors (including soil bulk density, nutrient, moisture and oxygen concentration, temperature, EC, and pH of the soil) when determining organic matter decomposition (Blakely et al., 2002). According to Galitskaya et al. (2014), in testing several techniques, adding compost to the petroleum contaminated soil, significantly promote bioremediation in most cases. Respecting microorganism's activity, the presence and amount (concentration) of the hydrocarbon substances is a crucial factor. As mentioned by Amellal et al. (2001), the distribution of microbes in the soil differ between, contaminated and uncontaminated soils. Abiotic factors can greatly influence the rate of crude oil biodegradation (Sonawdekar, 2012). As reported by Phillips et al. (2012) the biodegradation of petroleum hydrocarbons in loamy and sandy soil under proper SOM content and favorable degradation conditions of microorganism is, inversely proportional to the concentration of the contaminants. The hydrocarbons of crude oil were totally or partially biodegraded: low molecular weight n-alkanes were completely degraded by oil degraders while the high molecular weight n-alkanes are less degradable (Moubasher et al., 2015). Branched alkanes are resistant to biodegradation as, compared with n-alkanes and also aromatic hydrocarbons which are more resistant to microbial attack than n- and branched alkanes (Riser-Roberts, 1998).

Conflict of Interests

The authors have not declared any conflict of interests.

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