1. Introduction

At global level, crude oil productions are estimated to be more than twelve million metric tons annually and about 1.7 to 8.8 million metric tons of oil are released into the aquatic environment and soil respectively per annum. About 90% of this emission is directly related to human activities including deliberate illegal waste disposal. Fuel oil may enter the water or soil environment as a result of spillages during transportation and by leakages from the storage facilities or pipelines. The more volatile components of fuel oils (low molecular weight alkanes) can be degraded in both water and soil and could get evaporated from there and enter into the atmosphere where they will form contaminants.

Remediation of petroleum-contaminated systems can be achieved by physical, chemical or biological methods. However, the unattended negative consequences of physical and chemical approaches are currently directing greater attention to the use of the biological alternatives. An alternative method to remediate soil polluted by organic compounds is phytoremediation, where plants have been able to reduce organic contaminant by principally providing an optimal environment for microbial proliferation in the root zone (rhizosphere). These degradative processes are influenced not only by rhizosphere microorganisms, but also by the unique properties of the host plant. Plant exudates and sloughed tissue may enhance the degradation of the complex compounds due to increased bioavailability of the contaminants and the interaction among microbes, nutrients and contaminants. This often leads to enhanced breakdown of organic contaminants in vegetated soil area, compared to its opposite scenario.

If plants can be successfully established on polluted soils, then the plant-microbial interaction in the rhizosphere may provide an effective method for enhancing microbial degradation of complex organic contaminants. Many studies have shown that microbial population increased in soil contaminated with hydrocarbons. April and Sims (1990) reported the effect of prairie grasses on the biodegradation of four PAHs and reported that the disappearance of PAHs was greater for all the vegetated soils compared to unvegetated soil. By growing plants on diesel oil contaminated soil, optimal conditions are required for the microbial degradation of the contaminant to be enhanced. It has been estimated that more than 300 species of plants naturally absorb toxic materials from the environment. Very little work has been carried out in identifying contaminated sites in Malaysia. Contaminated land can

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[Research Note]

Diesel Fuel Degradation from Contaminated Soil by *Dracaena reflexa* Using Organic Waste Supplementation

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The phytoremediation potential of *Dracaena reflexa* to remediate diesel contaminated soil was determined in a greenhouse study. *D. reflexa* was planted in soil contaminated with different concentrations of diesel fuel (1, 2.5 and 5 wt%). 5 (wt%) of three different organic wastes [tea leaf (TL), soy cake (SC) and potato skin (PS)] were mixed with the soil and monitored for 270 days. The results of the biodegradation of oil and its fractions showed a reduction of 90% and 98% of total petroleum hydrocarbons (TPHs) in soil amended with SC, at 2.5% and 1% fuel, respectively. It was observed that in the non-cultivated polluted soil the TPHs, were reduced by 24-27%. Soil amended with SC provided the greatest diesel fuel loss when compared to other organic waste supplements. *D. reflexa* roots did not accumulate hydrocarbons from the soil, but the number of hydrocarbon utilizing bacteria was high in the rhizosphere, thus suggesting that the mechanism of the oil degradation was via rhizodegradation. This study has shown that *D. reflexa* amended with organic wastes has a potential for biodegrading hydrocarbon-contaminated soil.

**Keywords**
Phytoremediation, Rhizodegradation, Degradation, *Dracaena reflexa*
be found at places such as petrol stations, fuel oil depots, industrial sites and sites with built-in underground oil storage facilities. High molecular weight (HMW) of PAHs is persistent in terrestrial ecosystems and their carcinogenic properties have resulted in numerous studies of contaminated soils. Diesel fuel has the highest content of PAHs and total aromatics which makes it increasingly more difficult to remediate\cite{14,15}. In this study \textit{D. reflexa} (commonly called Pleomele or the Song of India, belongs to the \textit{Dracaena} specie, a tropical native three to Malaysia, India and other tropical regions), has a dark green colored leaves with a high drought tolerance-level, hardness and its non-edible characteristics made it a choice plant for phytoremediation. This plant can be grown into small bushes with partly shade and reach a height of 4-5 m. This plant was used in NASA clean air study and has shown to help remove formaldehyde, xylene and trichloroethylene. The objective of this study is to determine the potential of \textit{D. reflexa} in removing hydrocarbons from soil. Also investigate the effects of different organic amendments on the ability of \textit{Dracaena} in removing hydrocarbons. In addition, the mechanism for the removal of hydrocarbon is discussed.

2. Methods

2.1. Sample Collection and Analysis

Soil was obtained from the Nursery section of the Asia-Europe Institute, University of Malaya, Kuala Lumpur in a sack and transported to the laboratory. Soil samples were air-dried in a dark room, mixed well, sieved through a 2-mm sieve for analysis. The diesel fuel was purchased from a petrol station in Petaling Jaya, Malaysia. As nitrogen and phosphorus are usually the limiting inorganic nutrients for oil-degrading bacteria, we used organic wastes as an inorganic nutrient source. Organic wastes which used in this study was collected from different locations, tea leaf (TL) and potato skins (PS) were collected from the Institute of Graduate Studies (IGS) canteen, University of Malaya, while soy cake (SC) was prepared in the laboratory, by soaked soybean in water and blended it then extraction of milk. \textit{Dracaena reflexa} (Song of India) has a strong root system\cite{16} in the same age (9 months with 15 cm) and size (propagated via herbaceous stem cuttings and was purchased from a greenhouse) was used for phytoremediation assays. This plant has more drought tolerance than most plants in dry soil under irregular watering condition. It is widely cultivated in India and Malaysia.

Total N content of soil used for phytoremediation and total N content of organic wastes were determined using the APHA-4500 method (American Public Health Association) by Kjeldahl Digestion; while phosphorous, was determinate by adopting American Society for Testing and Material method (ASTM D 5198) by inductively coupled plasma mass spectrometry (ICP-MS). HANNAHI 8424 model of pH meter was used to determine the pH on the scale 1 : 2.5 (wt%) soil/distilled water after 30 min equilibrium. The experimental design was a randomized complete block with triplicates.

2.2. Microcosm Setup

Two kilograms of unsterilized, air-dried soil was placed into each plastic bag with volume of about (12 cm × 12 cm). Soils were artificially contaminated with 1, 2.5 and 5 (wt%) (10,000, 25,000 and 30,000 mg/kg) of diesel fuel and thoroughly mixed. 5 (wt%) of different organic wastes (TL, SC and PS) were also mixed individually with the fuel-contaminated soil. The polluted soil samples containing organic wastes were allowed to stabilize (incubation period in order to reach equilibrium fractions) for 5 days before transplanting the plants into the contaminated soil. Plant control treatments consisting of soil without organic wastes were also set up. An additional control treatment was set up which comprised of autoclaved soil (at 121 °C and 15 psi for 1 h) containing 0.5 (wt%) sodium azide (NaN₃). It is interesting to note that the presence of sodium azide, used as a sterilizer, prevented biodegradation, was also set up to determine non-biological loss of diesel fuel from the soil. In total, 54 microcosms were set up at room temperature (30 ± 2 °C). The plants were monitored and watered every other day with tap water (100 mL) to prevent leaching from the plastic bags. The design of the experiment is shown in Table 1.

2.3. Sampling

Fifteen gram of soil samples from the phytoremediation experiments were collected monthly and analyzed immediately across nine months study duration. Soil samples were taken within the rhizosphere zone (root area) of \textit{Dracaena} from each plastic bag every 30 days for the analysis of total petroleum hydrocarbon (TPH), pH, total organic carbon and hydrocarbon utilizing bacterial (HUB) counts. At the completion of the experiment (270 days), the plants were uprooted. The root tissue was extracted with 1 : 1 hexane/acetone in a Soxhlet extractor for 10 h to determine if the roots had absorbed the hydrocarbon from the soil\cite{17}. To assess hydrocarbon content removal, the extracts were analyzed for hydrocarbons using gas chromatography (GC, 2010A) with a mass-selective detector (QP2010A). The GC was equipped with cross-linked 5 % phenyl methyl siloxane capillary column. Helium was used as the carrier gas. The temperature was set at 40 °C and raised by 10 °C/min until 300 °C, which was maintained for 8 min.

2.4. Microbial Plate Counts

The population of microorganisms in the rhizosphere of the petroleum contaminated soil was determined immediately after collecting sample by the serial dilution
before determining the fresh weight. Root length and stem height were also measured. Then the samples were oven-dried at 70 °C until the weight was constant and the dry weight was recorded\(^{21}\).

### 2.6. Kinetics of Diesel Removal and Half-life

First-order kinetics model was used and it was expressed by the following equation\(^{22}\):

\[
C_t = C_i \exp(-kt)
\]

Where \(C_i\) (mg/g), is the diesel fuel concentration in soil at instant \(t\), \(C_t\) (mg/g) is the initial concentration of soil, \(k\) is the rate constants of the first order expressed in (day \(^{-1}\)), and \(t\) is the time. The model estimated the biodegradation rate and half-life of hydrocarbons in soil relative to treatments applied.

\[
\text{Half-life} = \ln(2)/k
\]

Analysis of variance (ANOVA) with SPSS (version 18) was used to evaluate if plant/soil treatments accelerated removal of diesel fuel.

### 3. Results and Discussion

#### 3.1. Soil and Organic Wastes Characterization Used for Phytoremediation

The physicochemical properties of the investigated soil and organic wastes used in bioremediation are presented in Table 2. The native soil had a natural pH (~7) with low concentration of C, P and N compared to organic wastes. The soil used for bioremediation had C: N ratio of 16.4. This is a low ratio for effective biodegradation of oil in the soil, hence needed addition of organic wastes as a source of nutrients. Low N content (0.24 %) and P content (0.08 %) were recorded for soil (Table 2). Of the organic wastes used, SC had higher amount of N (1.3 %) compared to PS (1.1 %) and TL (1.02 %).

#### 3.2. Degradation and Phytoremediation of Soil TPHs by D. reflexa

The response of *D. reflexa* plant to 1, 2.5 and 5 wt% concentrations of fuel was monitored throughout the 270 days of the experiment. No plant death was recorded in the 1 % diesel fuel; however some of the plants in the 2.5 % fuel showed signs of phytotoxicity such as yellowing of leaves, and stunted growth compared with the control. The experiment was monitored for 150 days only but plants in 5 % fuel concentration all died within 150 days.

The results are in line with the findings of Vuillamoz and Mike (2009), who reported reduced growth rate in ryegrass planted in diesel contaminated soil\(^{21}\).

Changes in the concentrations of TPHs under different treatments and the corresponding controls are depicted in Figs. 1, 2 and 3. Some differences of TPHs degradation by *D. reflexa* are observed between the treatments and the controls in all concentrations. By

### Table 1  Experimental Setup and Treatments

| Treatment | Description |
|-----------|-------------|
| A         | 2 kg soil + 1 % oil + 5 % TL + *Dracaena reflexa* |
| B         | 2 kg soil + 1 % oil + 5 % SC + *Dracaena reflexa* |
| C         | 2 kg soil + 1 % oil + 5 % PS + *Dracaena reflexa* |
| D         | 2 kg soil + 1 % oil + *Dracaena reflexa* |
| E         | 2 kg soil + 1 % oil only |
| F         | 2 kg autoclaved soil + 1 % oil + 0.5 % NaN\(_3\) |
| G         | 2 kg soil + 2.5 % oil + 5 % TL + *Dracaena reflexa* |
| H         | 2 kg soil + 2.5 % oil + 5 % SC + *Dracaena reflexa* |
| I         | 2 kg soil + 2.5 % oil + 5 % PS + *Dracaena reflexa* |
| J         | 2 kg soil + 2.5 % oil + *Dracaena reflexa* |
| K         | 2 kg soil + 2.5 % oil only |
| L         | 2 kg autoclaved soil + 2.5 % oil + 0.5 % NaN\(_3\) |
| M         | 2 kg soil + 5 % oil + 5 % TL + *Dracaena reflexa* |
| N         | 2 kg soil + 5 % oil + 5 % SC + *Dracaena reflexa* |
| O         | 2 kg soil + 5 % oil + 5 % PS + *Dracaena reflexa* |
| P         | 2 kg soil + 5 % oil + *Dracaena reflexa* |
| Q         | 2 kg soil + 5 % oil only |
| R         | 2 kg autoclaved soil + 5 % oil + 0.5 % NaN\(_3\) |
| S         | 2 kg soil + *Dracaena reflexa* |

Triplicate setup used for all treatment. Percentage is according to weight of soil.

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* method\(^{18}\). Hydrocarbon utilizing bacteria (HUB) counts in the soil was determined by plating a serially diluted sample into test tube with 1 g of soil on oil agar (OA) [1.8 g K\(_2\)HPO\(_4\), 4.0 g NH\(_4\)Cl, 0.2 g MgSO\(_4\)·7H\(_2\)O, 1.2 g KH\(_2\)PO\(_4\), 0.01 g FeSO\(_4\)·7H\(_2\)O, 0.1 g NaCl, 20 g agar, 1 % (vol%) diesel oil in 1000 mL distilled water, pH 7.4], and 10\(^7\) dilution was incubated at 30 °C for 72 h. The colonies on each plate were counted and recorded as colony forming unit per gram of soil (CFU/g). The pure culture of the bacterial isolates was identified by the Biolog method at the Dental Faculty, University of Malaya.

The total extent of diesel fuel biodegradation in soil was determined by suspending 10 g of soil in 20 mL of acetone : hexane (1 : 1 vol%) in a 250 mL capacity Erlenmeyer flask. After shaking for 1 h on a orbital shaker (Model N-Biotek-101), the solvent-oil mixture was filtered using Whatman filter paper into a beaker of known weight and the solvent was completely evaporated by rotary evaporation (A1000S). The new weight of the beaker (now containing residual oil) was recorded. Percentage biodegradation of used oil was calculated using the formula of\(^{17,19}\):

\[
\% \text{ biodegradation} = \frac{\text{weight of oil (control) } - \text{weight of oil (degraded)}}{\text{weight of oil (control)}} \times 100
\]

#### 2.5. Determination of Biomass

The biomass of *D. reflexa* growing under diesel fuel stress and in clean soil (the control) was measured. Plants were removed from the soil and shook to dislodge excess soil attached to the roots\(^{20}\). Prior to the analysis, plant samples were carefully washed with tap water and thoroughly rinsed with deionized water to remove any soil particles attached to the plant surfaces and wiped with filter paper to remove excess liquid.
soil. The degradation of TPHs at 1 % diesel by Dracaena, 0.5 % NaN₃. Error bars indicate SE (1 % fuel).

### Physical and Chemical Properties of Soil and Organic Wastes Used for Phytoremediation

| Parameters          | Soil                  | TL         | SC         | PS         |
|---------------------|-----------------------|------------|------------|------------|
| Total nitrogen (%)  | 0.2 ± 0.5             | 1.0 ± 0.1  | 1.3 ± 0.1  | 1.1 ± 0.1  |
| Phosphorous [mg/kg] | 0.6 ± 0.5             | 0.79 ± 0.68| 0.9 ± 0.9  | 0.7 ± 0.1  |
| Moisture content [%] | 8 ± 0.6               | 34.3 ± 0.5 | 75.9 ± 1.6 | 62.1 ± 2.0 |
| Organic carbon [%]  | 0.7 ± 0.9             | 0.9 ± 1.2  | 1.2 ± 0.9  | 1.1 ± 0.4  |
| pH                  | 6.4 ± 0.6             | 6.5 ± 1.2  | 6.2 ± 1.2  | 6.9 ± 0.5  |
| AHB [CFU/g]         | 2.6 × 10⁷             | 4 × 10⁷    | 8.6 × 10⁷  | 5.6 × 10⁷  |
| Silt [%]            | 70 ± 2.5              | -          | -          | -          |
| Sand [%]            | 20 ± 1.8              | -          | -          | -          |
| Clay [%]            | 10 ± 1.6              | -          | -          | -          |
| Texture             | Silty loam            | -          | -          | -          |

TL: Tea Leaf, SC: Soy Cake, PS: Potato Skin, AHB: Aerobic Hydrocarbon Bacteria. CFU: Colony Forming Unit.

Standard error (n = 3).

by natural attenuation (Fig. 1).

Approximately 46-59 % of the diesel fuel was lost in the first two months by soil amendment with SC and 1 % fuel, presumably by volatilization and sorption in soil. This loss rate was similar to that reported in Dible and Bertha (1979), which showed that in drummed oily waste approximately 50 % of TPH would be lost after 6-weeks, mainly due to volatilization and weathering. High loss of oil in soil treated with SC and Dracaena plants may be due to the presence of appreciable amounts of N (1.3 %) in SC (Table 2). This was also recorded in previous work, where soil amended with SC recorded 67-78 % loss of diesel fuel in soil.

It was also noticed that D. reflexa plant amended with SC grew better and taller (about 25 % more than other treatments) with lots of fibrous roots than other treatments in the experimental set up. The result is similar to that of (Palmroth et al., 2002), who recorded 60 % loss of diesel fuel in 30 days in diesel contaminated soil planted with pine tree and amended with NPK fertilizer. It has been found that the best reduction in TPH in vegetated treatments occurred when the fertilizer ratio was 100 : 2 : 0.2 (C : N : P). It is noted that this research is focus on organic wastes (biowastes) as supplements.
which are available, cheap and for easy application to remediate soil rather than inorganic fertilizers which are expensive and also can be wash by rain and goes to river and ground water and lead to water pollution. This way could be an option to waste management especially in those areas that generated high rate of food, vegetables and fruit wastes. It is also related to the findings of Dominguez-Rosado and Pichtel (2005) that recorded 67% degradation of used motor oil in oil contaminated soil planted with sunflower and mustard plants. Statistical analysis showed that there was significant differences between the soil treated with different organic wastes, soil with only Dracaena plants and soil without Dracaena plants, and also among the soil treated with SC and soil amendment with TL at (P < 0.05).

These results indicated that the addition of organic wastes to contaminated soil, planted with Dracaena, increased the loss of oil in the soil by almost 25%; this is in line with the findings of Vouillamoz and Milke (2009), who observed that compost addition combined with phytoremediation, increased the rate of removal of diesel fuel in soil23). At 180 days, 80% of added diesel fuel remained in the non-vegetated treatment with no waste amendment (control treatment) and it showed that diesel concentration decreased in the control treatment slowly as compared to other soil amendments. 11% of oil loss observed at the end of the experiment in autoclaved control that might be due to photolysis, evaporation loss or amount of sodium azide (0.5%) that did not effectively sterilize the soil; Namkoong et al. (2002) found that a concentration of 1% sodium azide affected the evaporation of chlorobenzene in sludge-amended soil and the structure of the soil30).

3.3. Bacterial Counts

Aerobic heterotrophic bacterial (AHB) counts in D. reflexa remediated soil ranged from $208 \times 10^7$ to $338 \times 10^7$ CFU/g, in all the treatments amended with organic wastes, while the unamended treatments recorded low counts of AHB which ranged from $8 \times 10^7$ to $86 \times 10^7$ CFU/g which is 18.8% and 39% higher than that of amended with PS and TL, respectively. The counts of hydrocarbon utilizing bacteria (HUB) in soil contaminated with different treatments at 2.5% and 1% diesel fuel are shown in Figs. 4 and 5. At the end of 270 days contaminated soil treated with SC and Dracaena remediation shows high counts of HUB ($355 \times 10^4$ and $378 \times 10^4$ CFU/g) in both soil contaminated with 2.5% and 1% oil, respectively, which is similar to the findings of Ijah and Antai (2003)30). Whereas the treatment with only Dracaena plant without organic wastes amendment recorded low counts of HUB ($92 \times 10^3$ and $111 \times 10^3$ CFU/g) in 2.5% and 1% pollution, respectively. At the first of experiment the number of HUB in soil polluted with 1% oil and amended with SC, TL and PS recorded 0.76, 0.5 and $0.6 \times 10^9$ CFU/g, respectively; whereas in soil polluted with 2.5% oil was 0.5, 0.3 and $0.4 \times 10^9$ CFU/g, respectively. Contaminated soil polluted with 1% and 2.5% oil without Dracaena recorded 0.2 and 0.1 $10^9$ CFU/g, respectively. In addition, low counts of HUB and AHB were recorded in soil without plant and organic wastes. However, those treatments amended with SC are shown higher number of AHB and DUB in both concentration of diesel fuel. The reason for the increase in bacteria population in contaminated soil amended with organic wastes might be due to the presence of nutrients in the organic wastes especially, N and P, which enhanced the proliferation of bacteria in the soil. The results are similar to the finding of Muratova et al. (2003) who reported heterotrophic microorganisms that are able to degraded oil was significantly increasing by stimulating plant compare to no plant contaminated soil. They observed that the amount of PAH oxidizing microorganisms was seven times higher in the rhizosphere of alfalfa and in the case of reed was four times lower in the rhizosphere than control soil30). The HUB isolated from the contaminated soil was identified as species of Pseudomonas,
Bacillus amyloliquefaciens, Microbacterium barkeri, and Micrococcus sp. These bacterial species together with root exudates of the Dracaena plants possibly helped in the removal of diesel fuel from the soil.  

### 3.4. Plant Uptake of Diesel Hydrocarbons

Hydrocarbon concentrations in shoot and root tissue were analyzed to determine if phytoaccumulation and phytodegradation played a role in the diesel fuel removal. Gas chromatographic mass spectrometry (GC/MS) analysis of the plant extract did not show any presence of hydrocarbons for all the treatments. This is in sharp contrast with the results of Palmroth et al. (2002), who observed an uptake of diesel oil by grass root. The differences might be due to the different plants used in the studies; it might also be due to differences in the weather conditions as studied by Palmroth et al. (2002). Radwan et al. (2000) found that long-chain hydrocarbons accumulated in broad bean (Vicia faba) grown in oily soil. The accumulation, especially in the seeds, was thought to pose a risk to human or animal nutrition. The result suggests that the mechanism of hydrocarbon removal by the Dracaena plants may be via rhizodegradation which has been well documented. Also, the removal of the oil may be the result of root exudates produced by the D. reflexa plant which enhanced the activities of soil microorganisms in mineralizing the oil in the soil. This is supported by the findings of different authors, who stated that flavonoids and other compounds released by roots can stimulate growth and activity of hydrocarbon degrading bacteria.  

In addition, root growth and death are known to promote soil aeration which can enhance oxidative degradation of organic contaminants.  

### 3.5. Biomass Production

In order to further assess the endurance of the plant species to petroleum contaminated soil, D. reflexa was planted in soil containing different concentrations of petroleum contaminants. Different parameters including stem height, fresh weight, dry weight, root length, root weight, and growing rate were measured and recorded. At the initial three weeks after planting, all plants growing in petroleum contaminated soil showed no visible differences in appearance with those in the corresponding controls, although there was a little inhibition of the plants growing in treatment with 5 % fuel, compared with those planted in clean soil. After 270-day exposure, the highest of D. reflexa longitudinal growth was observed in the amendment with SC contaminated soils with 1 % and 2.5 % of petroleum hydrocarbons “20 % and 36 % higher than that of the plants growing in clean soil, respectively.” Biomass of 2.5 % oil contaminated soil (SC amended) was 1.8 and 4.7 times more than treatments amended with PS and TL. Also, the result indicated that the biomass of treatment at 1 % oil amended with SC was 1.8 and 2.7 times more than treatment amended with PS and TL, respectively. Followed by increasing biomass of 1.1 times more in SC amendment at 1 % diesel fuel compared to unamended soil. The development of the plants during the 270-day cultivation period was also evaluated by measuring the dry weight of the plants. It was observed that the biomass of D. reflexa growing in soil amended with SC and 1 % diesel did not decrease significantly as compared to that in the corresponding control, although the change in the biomass of the plants depended on the level of petroleum contaminants in soil (Table 3). Noticeably, there was 65 % decrease in the biomass of the plants growing in high concentration (5 % diesel fuel) of petroleum contaminants; D. reflexa species was still alive although some chlorosis was observed in leaves. Thus, D. reflexa is likely to had phytoremediated diesel fuel contaminated soil with a concentration ≤ 5 % (50 g/kg) on the basis of the endurance of the species.  

### 3.6. Kinetics of Diesel Removal and Half-life

First-order kinetics model was used for determination of degradation of diesel oil in the various treatments. Table 4 shows the degradation rate constant (k) and half-life (t_{1/2}) for the different treatments. Soil amended with SC had the highest degradation rate of 0.133 day^{-1} and half-life 5.21 days at 1 % concentration oil. The degradation rate of PS and TL were 0.096 day^{-1} and 0.071 day^{-1} at 1 % concentration and 0.077 day^{-1} and 0.055 day^{-1} at 2.5 % concentration. The degradation rate of unamended control and autoclaved soil were 0.038 day^{-1} and 0.0078 day^{-1} at 1 % concentration, respectively. This result is similar to the findings of Namkoong et al. (2002) that reported higher degradation rate constant and low half-life in diesel

| Treatment | Leaves | Stem | Roots |
|-----------|--------|------|-------|
| A         | 4.3 ± 0.9 | 3.0 ± 0.3 | 1.2 ± 0.2 |
| B         | 8.4 ± 1.2 | 9.3 ± 0.6 | 5.5 ± 0.1 |
| C         | 5.8 ± 0.2 | 4.1 ± 1.6 | 3.1 ± 0.6 |
| D         | 1.6 ± 0.7 | 2.6 ± 1.1 | 0.9 ± 0.3 |
| G         | 1.8 ± 1.2 | 0.8 ± 0.2 | 0.5 ± 0.2 |
| H         | 5.6 ± 1.1 | 6.7 ± 0.3 | 2.3 ± 0.6 |
| I         | 3.3 ± 1.4 | 2.8 ± 0.7 | 1.9 ± 0.1 |
| J         | 1.1 ± 0.7 | 1.8 ± 0.6 | 0.6 ± 0.2 |
| M         | 0.7 ± 0.4 | 0.4 ± 0.1 | 0.4 ± 0.1 |
| N         | 2.1 ± 0.8 | 3.3 ± 0.2 | 1.2 ± 0.2 |
| O         | 1.7 ± 0.9 | 1.3 ± 0.7 | 0.8 ± 1.1 |
| P         | 0.6 ± 0.1 | 0.2 ± 0.6 | 0.4 ± 0.2 |
| S         | 7.6 ± 0.2 | 9.2 ± 1.5 | 4.8 ± 0.3 |

A, soil + 1 % oil + TL; B, soil + 1 % oil + SC; C, soil + 1 % oil + PS; D, soil + 1 % oil only; G, soil + 2.5 % oil + TL; H, soil + 2.5 % oil + SC; I, soil + 2.5 % oil + PS; J, soil + 2.5 % oil only; M, soil + 5 % oil + TL; N, soil + 5 % oil + SC; O, soil + 5 % oil + PS; P, soil + 5 % oil only; S, control soil i.e. without oil contamination. Standard error (n = 3).
The results of this study demonstrated the potentials of *D. reflexa* together with organic wastes amendments to remediate hydrocarbon contaminated soil. Though no accumulation of hydrocarbon was detected in the plant tissue, the use of *D. reflexa* will therefore serves as an alternative method in removing oil contaminants. The degradation of diesel fuel and its components was 13-30 % higher than that of control. Addition of organic waste, especially SC to the contaminated soil further enhanced the growth of *Dracaena* and proliferation of bacteria in the soil. Oil loss from the soil might be through rhizodegradation mechanism. This affords an alternative method in removing oil contaminants from soil while promoting growth of economically viable plant like Song of India.

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References
1) EIA, “US Environmental Information Agency, China electricity,” (2011).
2) Denys, S., Rollin, C., Guillot, F., Baroudi, H., *Water Air Soil Pollut Focus*, 6, 299 (2006).
3) Jacks, G., Forsberg, J., Mahgoub, F., Palmqvist, K., *Ecological Eng.*, 15, 147 (2000).
4) Kaimi, E., Mukaidani, T., Miyoshi, S., Tamaki, M., *Environ. Exp. Bot.*, 55, 110 (2006).
5) Banks, M., Schwab, P., Liu, B., Kulakov, P., Smith, J., Kim, R., *Adv. Biochem. Eng. Biotechno.*, 78, 75 (2003).
6) Alkorta, I., Garbisu, C., *Bioresource Technol.*, 79, 273 (2001).
7) Gerhardt, K. E., Huang, X. D., Glick, B. R., Greenberg, B. M., *Plant Science*, 176, 20 (2009).
8) Glick, B. R., *Biotechnology Advances*, 21, 383 (2003).
9) Aprill, W., Sims, R. C., *C hemosphere*, 20, 253 (1990).
10) Adam, G., Duncan, H., *Environmental Pollution*, 120, 363 (2002).
11) Radwan, S. S., Al-Awadhi, H., El-Nemr, I. M., *Int. J. Phytoremediation*, 2, 383 (2000).
12) Cunningham, S. D., Anderson, T. A., Schwab, A. P., Hsu, F. C., “Phytoremediation of Soils Contaminated with Organic Pollutants,” Advances in Agronomy Academic Press, (1996), pp. 55-114.
13) Lee, H. K., Hanili, G., Mohd Jan, I. K., “Guide control in Malaysianines for contaminated land management and Control Guidelines: Assessing and Reporting Contaminated Sites,” Dept. Environment of Ministry of Natural Resources and Environment, Kuala Lumpur, Malaysia, 2, (2009), pp.1- 48.
14) Betancur-Galvis, L., Alvarez-Bernal, D., Ramos-Valdivia, A., Denoooven, L., *Chemosphere*, 62, 1749 (2006).
15) Lin, X., Li, X., Li, P., Li, F., Zhang, L., Zhou, Q., * Bull. Environ. Cont. & Toxi.*, 81, 19 (2008).
16) Lay, P. T., Teik, T. L., He, J., Proceedings of the 10th International conference on Environmental Science and Technology, Kos island, Greece, 5-7 September, (2007), p. 1400.
17) Abioye, P., Agamuthu, P., Abdul Aziz, A. R., *Biodegradation*, 23, 277 (2011).
18) Nanjing Institute of Pedology, “C. o. S., Method of Studying on Soil Microbiology,” Science Press, Beijing (1985).
19) Ijah, U. J. J., Ukpe, L. I., *Waste Management*, 12, 55 (1992).
20) Phillips, L. A., Greer, C. W., Germida, J. J., *Soil Biology & Biochemistry*, 38, 2823 (2006).
21) Merkl, N., Kraft, R. S., Arias, M., *Microbiological Research*, 161, 80 (2006).
22) Chu, W., Chan, K. H., *The Science of The Total Environment*, 307, 83 (2003).
23) Vouillamoz, J., Milke, M. W., *Water Science Technology*, 43, 291 (2009).
24) Dibble, J., Bartha, R., *Appl. Environ. Microbiol.*, 37, 729 (1979).
25) Dadrasnia, A., Agamuthu, P., *Malaysian Journal of Science*, 29, 225 (2010).
26) Hutchinson, S. L., Banks, M. K., Schwab, A. P., *J. Environ. Qual.*, 30, 395 (2001).
27) Dominguez-Rosado, E., Pichtel, J., *Journal of Environmental Science and Health*, 39, 2369 (2005).
28) Namkoong, W., Hwang, E.-Y., *Park, J.-S., Choi, J.-Y.*, *Environmental Pollution*, 119, 23 (2002).
29) Ijah, U. J. J., Antai, S. P., *International Biodeterioration & Biodegradation*, 51, 93 (2003).
30) Muratova, A. Y., Turkovskaya, O. V., Hübner, T., Kuschk, P., *Applied Biochemistry and Microbiology*, 39, 599 (2003).
31) Corgie, *Applied Environmental Microbiology*, 70, 3552 (2004).
32) Adam, G., Duncan, H., *Environmental Pollution*, 120, 363 (2002).
33) Muratova, A.Y., Turkovskaya, O. V., Hübner, T., Kuschk, P., *Applied Biochemistry and Microbiology*, 39, 599 (2003).
34) Palmroth, M. R. T., Pichtel, J., Puhakka, J. A., *Bioresource Technology*, **84**, 221 (2002).

35) Adesodun, J. K., Mbagwu, J. S. C., *Bioresource Technology*, **99**, 5659 (2008).