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Various physical, chemical, and biological methods have been used to clean up petroleum hydrocarbons pollution. Among these, phytoremediation is a friendly, low-cost, and innovative method to use the plant to reduce many organic and inorganic pollutants and has been used to monitor soil pollution [11, 12]. However, soil contamination can negatively affect phytoremediation efficiency by reducing plant biomass. On the other hand, in the central regions of the country, salinity and drought stress [13, 14] as two plant stressors have a negative impact on plant growth. Thus, it is necessary to look for appropriate solutions to deal with these stressors. Accordingly, Mousavi Kouhi et al. (2020) investigated the phytoremediation potential of native plant species naturally growing in a heavy metal-polluted saline-sodic soil and concluded that saline soils can increase the availability of heavy metals and can decrease the plant biomass that is an important factor in phytoremediation efficiency. However, they did not consider the simultaneous effect of heavy metal contamination with petroleum compounds and their role on phytoremediation efficiency [15]. Therefore, it is necessary to look for a suitable solution to reduce the negative effects of plant stress such as salinity and drought which can help increase the efficiency of phytoremediation. In this regard, Zamani et al. (2016) reported that plant rhizosphere microorganisms can help to increase the plant resistance to abiotic stresses. However, they did not consider the plant abiotic stresses such as drought or salinity [16]. On the other hand, the results of several researchers showed that plant inoculation with Piriformospora indica (P.indica) can help to increase plant growth which may enhance the soil microbial activity that a positive role on biodegradation of petroleum hydrocarbons in the soil [16, 17]. P.indica has been a well-known and most studied entophytic fungus for vegetative growth and resistance to plants since past decades. Zamani et al. (2018) investigated the effect of P.indica on the degradation of petroleum hydrocarbons in the soil and concluded that inoculation of corn with P.indica had a significant effect on increasing the plant growth and enhancing the biodegradation of petroleum hydrocarbons in the soil [16]. On the other hand, the physiology and plant cultivation system can have a positive effect on soil microbial activity and thus the decomposition of petroleum compounds in the soil, which needs to be studied in separate studies for each plant and in different soil physico-chemical conditions [18].

Today, the problem of simultaneous soil contamination with heavy metals and petroleum compounds is one of the main issues of the country's industrial areas and remediation of these areas depends on the physical and chemical characteristics of the soils of each region and its climatic characteristics. Among these, salinity and drought stresses in arid and semi-arid regions are two plant abiotic stresses that can restrict the plant biomass [19] and thereby decrease the plant phytoremediation efficiency [20] or biodegradation of petroleum hydrocarbons in the soils [21]. One of the effective solutions is changing the cultivation pattern such as intercropping system or plant inoculation with symbiotic bacteria such as P.indica which can reduce the negative effects of salinity, drought, or heavy metals stresses. However, the plant type, climate condition, and soil physicochemical properties can have different effects on phytoremediation efficiency that should be considered in different researches. Thus, this research was carried out to evaluate the effect of plant inoculation with P.indica fungus, drought, and salinity stress on biodegradation of diesel oil in a Pb and Cd contaminated soil under cultivation of corn and white clover intercropping system.

2. Materials and Methods

To investigate the effect of P.indica fungus, drought, and salinity stress on biodegradation of diesel oil in a Pb and Cd contaminated soil under cultivation of corn and white clover intercropping system, a soil with low organic carbon that was naturally polluted with Pb and Cd was selected. Selected physicochemical properties of studied soil were shown in Table 1.

Treatments consisted of corn and white clover intercropping system which were as a main crop and intercrop, respectively, with three plant densities of white clover (0, 20, and 30 seeds per pots). In addition, corn was inoculated with P.indica under soil salinity (initial salinity and 6 ds/m) and water stress (Normal (D0)) and intensive (D1) and was cultivated in the soil that was artificially polluted with diesel oil at the ratio of 0 and 4 % (W/W) and naturally contaminated with Pb (600 mg/kg soil) and Cd (mg/kg soil). This research was done as factorial experiments in the layout of a randomized completely block design with three replications. To perform this experiment, the Pb and Cd-polluted soil was contaminated with diesel oil at the rates of 0 and 4 % (W/W) and incubated for one month to equilibrium. After that, soil salinity was applied and the initial salinity of soil was considered as a treatment.

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Table 1: Selected soil physico-chemical properties

| Characteristic | Unit | Amount |
|---------------|------|--------|
| Soil texture  | -    | Silt loam |
| pH            | -    | 7.0    |
| EC            | ds/m| 3.1    |
| Pb available  | mg/kg soil | 600  |
| Cd available  | mg/kg soil | 15   |
| As available  | mg/kg soil | ND*  |
| Organic carbon| %    | 0.1    |
| CaCO3         | %    | 8      |

*ND: Not detectable by atomic absorption spectroscopy (AAS)
After that, soil salinity was applied and the initial salinity of soil was considered as a treatment. For increasing the soil salinity from 3.1 (initial salinity of soil) to 6 dS/m, the studied soil was irrigated several times with saline water to reach the equilibrium of soil EC equal to 6 dS/m. these rates of salinity were selected to find out the role of experimental treatments on plant growth in saline soils (EC=4 dS/m). The climate condition in the greenhouse was set up in 14h photoperiod, relative air humidity of 45-45% and temperature of 22/17 °C (day/night). Soil moisture in normal conditions was controlled at 70% of the total water holding capacity (FC) during the experiment by daily watering. The intensive drought stress (D1) was designed at the permanent wilting point (PWP) when the plant has a problem with water supply.

Three days after seed germination on filter paper, the corn seedlings (as the main crop) and white clover (as an intercrop) were transferred into 5 kg plastic pots (two seedlings in each pot) as a monoculture and intercropping system and filled with the treated soil. Two fungal plugs of 10 mm in diameter were placed at a distance of 1 cm below the corn and white clover seedlings in the soil at sowing time. P. indica was prepared from the soil and water research institute, Tehran, Iran. Plants were irrigated under normal (full irrigation (D0)) and intensive (70% water depletion of field capacity) drought stress (D1). After 10 weeks of plant growth, the percentage of diesel oil degradation of diesel oil in the soil was measured using the GC with a Delsi DI 200 chromatograph equipped with a direct injection port and an FID detector at 340 °C. The carrier gas was helium under 0.08 MPa and the column was a CP Sil 5 CB (Chrompack) capillary column (50 m by 0.32 mm, film thickness 0.25 µm). The soil microbial respiration as an index of soil activity was determined as evolved CO2 according to the method that was described by Besalatpour et al. (2011) [22]. Peroxidase (POX) [23] and ascorbate peroxidase (APX) enzyme activity were also determined [24].

2.1. Statistical analysis

A completely block randomized design in three replications was used. The statistical analyses of data were performed using the ANOVA procedure. Differences between means were evaluated using the least significant difference (LSD test). The 0.05 probability value was used to determine the significant difference.

3. Results and Discussion

The greatest degradation percentage of diesel oil in the soil (Table 2) belonged to the soil under cultivation of plants (intercropping system) inoculated with P.indica, while the lowest was measured in the absence of P.indica under salinity and drought stress. Using corn and white clover intercropping system significantly increased the biodegradation of diesel oil in the soil, as, the results of the current study showed that using corn in intercropping relative to mono-culture system significantly increased the degradation of diesel oil in the soil by 13.1% that may be related to the role of plant resistance to abiotic stresses [25] and consequently increase the plant root exudate that can help to increase the diesel oil degradation in the soil [26]. The results of a study by Bian et al. (2021) indicated that [18] using the intercropping system can enhance the phytoremediation of heavy metal efficiency through changes in the soil rhizosphere properties that are similar to our results [18].

In addition, increasing the soil microbial respiration (Table 3) with increasing the diesel oil percentage in the soil can indicate that petroleum hydrocarbons in the soil can be used as a carbon source for soil micro-organisms [27]. However, the highest level of petroleum hydrocarbon pollution may soil microbial respiration adversely. In this regard, Mitter et al. (2021) investigated the impact of diesel and biodiesel contamination on soil microbial community activity and structure and concluded that increasing the soil pollution with petroleum hydrocarbons had adverse effects on soil microbial respiration [28].

Table 2: Effect of corn and white clover intercropping, soil salinity, drought stress, and diesel oil on biodegradation of diesel oil (%) in the soil in the presence and absence of P.indica

| Drought stress | Corn to white clover ratio | Diesel oil (% W/W) | P.indica (+) | Soil salinity (dS/m) | P.indica (-) |
|---------------|---------------------------|-------------------|-------------|----------------------|-------------|
| D0            | 1:10                      | 0                 | NC**        | NC                   | NC**        |
|               |                            | 4                 | 68.1d*      | 62.7i                | 64.3g       |
|               |                            | 1:20              | NC          | NC                   | NC          |
|               |                            | 4                 | 70.1c       | 65.4f                | 67.7e       |
|               |                            | 1:30              | NC          | NC                   | NC          |
|               |                            | 4                 | 72.4a       | 68.3d                | 71.1b       |
| D1            | 1:10                      | 0                 | NC          | NC                   | NC          |
|               |                            | 4                 | 65.1f       | 60.5k                | 62.1i       |
|               |                            | 1:20              | NC          | NC                   | NC          |
|               |                            | 4                 | 68.3d       | 62.5i                | 64.2g       |
|               |                            | 1:30              | NC          | NC                   | NC          |
|               |                            | 4                 | 70.3c       | 65.4f                | 67.3e       |

*Data with similar letters are not significant (P< 0.05), **NC: Not measured, D0 and D1 are normal and intensive drought stress, respectively.
In this regard, Mitter et al. (2021) investigated the impact of diesel and biodiesel contamination on soil microbial community activity and structure and concluded that increasing the soil pollution with petroleum hydrocarbons had adverse effects on soil microbial respiration [28]. It seems that the effect of petroleum hydrocarbons on soil microbial activity in different areas depends on the soil physico-chemical properties that should be studied in different conditions. In this regard, Baghaie et al. (2020) investigated the effect of corn and white clover intercropping on biodegradation of diesel oil in arsenic-contaminated soil in the presence of P.indica and concluded that cultivation of corn and white clover in an intercropping system can increase the biodegradation of diesel oil in the contaminated soil. However, they did not consider the role of plant abiotic stresses such as drought or salinity toxicity and their role in degradation of petroleum hydrocarbons in the soil [29]. In addition, increasing the corn to white clover can improve the biodegradation of diesel oil in the soil. The results of the present study showed that increasing the corn to white clover ratio from 1:0 to 1:20 and 1:30 significantly increased the biodegradation of diesel oil in the soil by 14.5% and 13.5% under normal conditions (without any stress). For salinity and drought stress, they were increased by 10.1 and 12.2%, respectively. Generally, P.indica has been a well-known and most studied entophytic fungus for vegetative growth and resistance to abiotic stresses that is the main objective of our study [33].

Salinity and drought stress had a significant effect on decreasing the biodegradation of diesel oil in the soil. Based on the results of our study, increasing soil salinity from 2 to 6 dS/m significantly decreased the biodegradation of diesel oil in the soil by 14.3% that can be related to the role of soil salinity on increasing the heavy metal availability and thereby decrease the soil microbial activity that has an important role on biodegradation of diesel oil in the soil [34]. Khoshgoftarmanesh et al. (2004) investigated the effects of soil salinity on soil and plant Cd concentration and concluded that saline irrigation water can increase the soil Cd availability and thereby increase the plant Cd uptake [35]. In addition, Zhang et al. (2020) evaluated the effect of salinity on Cd distribution and accumulation in two contrasting halophytes, Suaeda glauca and Limonium aureum and concluded that soil salinity had a significant effect on Cd uptake by plants [36]. Generally, salinity can influence the Cd solubility by the formation of Cd-chloride complexes or instigating sodium competition at the adsorption sites of soil particles, which have been shown to increase the activity and bioavailability of Cd, causing more Cd to be absorbed by plants [37].

The interaction effects of drought and salinity stress on diesel oil biodegradation in soil were also significant. However, the cultivation system had also a significant effect on bio-degradation of diesel oil in the soil. Accordingly,
a significant decrease was observed in biodegradation of diesel oil in the soil by 17.3%, when the corn (mono-culture system) was exposed to salinity and drought stress. Although this reduction was less in the intercropping system which can be attributed to the role of the intercropping system on increasing the plant resistance to environmental stresses such as salinity or drought stresses and possibly increases the soil microbial activity via consumption of carbon compounds in root secretions. Increasing soil microbial activity (Table 3) in corn and white clover intercropping system relative to corn mono-culture confirms our results. Minai et al. (2006) investigated the role of salinity on system relative to corn mono-culture confirms our results.

The highest APX (Table 4) and POX (Table 5) enzyme activity has belonged to the corn cultivated in a mono-culture system under salinity and drought stress in the absence of P.indica, while the lowest was measured in the corn cultivated in the intercropping system under normal condition. Regardless of the cultivation system, plant cultivation under drought or salinity stress significantly increased the APX or POX enzyme activity. However, the APX or POX enzyme activity was lower under intercropping relative to monoculture system. Accordingly, a significant decrease in APX enzyme activity was observed under drought and salinity stress by 11.3 and 14.2%, respectively, when the corn was cultivated in intercropping relative to monoculture system which can be related to the role of white clover as a intercrop plant on increasing plant resistance to abiotic stress.

At this time, increasing the corn to white clover ratio also helped to increase the plant resistance to abiotic stresses. Increasing the corn to white clover ratio from 1:10 to 1:30 significantly decreased the APX enzyme activity by 13.1 and 15.2 %, respectively.

For the POX enzyme, similar results were observed. A significant decrease by 15.3 and 17.1% in APX and POX enzyme activity was observed when the corn cultivated in intercropping system inoculated with P.indica indicating that inoculation of plant with P.indica can improve the plant resistance among the abiotic stresses such as salinity or heavy metals toxicity.

Increasing the plant biomass (Table 6) in corn intercropping relative to monoculture system has significantly decreased the APX and POX enzyme activity and increased the biodegradation of diesel oil in the soil.

The remarkable point of this research is that the white clover planting as an intercrop has been able to increase the microbial respiration activity of the rhizosphere plant, and this has been able to increase the biodegradation of petroleum compounds in the soil. Increasing the plant biomass (Table 6) and soil microbial respiration (Table 3) in intercropping system indicated that using intercropping relative to monoculture system can increase the plant resistance to abiotic stress via increasing plant biomass and consequently increase the biodegradation of petroleum compounds in heavy metal polluted soil which is an important factor in environmental studies. In the meantime, increasing the corn to white clover ratio through increasing the white clover density in the intercropping system can help to increase the biodegradation of diesel oil in the soil. However, the salinity and drought stress had a significant effect on degradation of diesel oil in the soil. Generally, white clover as an intercrop plant can elevate the nitrogen fixation effect on degradation of diesel oil in the soil. For the POX enzyme, similar results were observed. A significant decrease by 15.3 and 17.1% in APX and POX enzyme activity was observed when the corn cultivated in intercropping system inoculated with P.indica indicating that inoculation of plant with P.indica can improve the plant resistance among the abiotic stresses such as salinity or heavy metals toxicity.

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Li et al. (2009) compared the effect of intercropping and mono-culture system on the plant growth in Cd polluted soil and concluded that using intercropping relative to monoculture system had a significant effect on the plant growth which attributed to the role of intercrop plants on

### Table 4: Effect of corn and white clover intercropping, soil salinity, drought stress, and diesel oil on APX enzyme activity (Unit/mg protein)

| Drought stress | Corn to white clover ratio | Diesel oil (% W/W) | P.indica (+) | P.indica (-) |
|----------------|----------------------------|--------------------|--------------|--------------|
|                |                            |                    | Initial salinity 6 | Initial salinity 6 |
|                |                            |                    | Soil salinity (dS/m) | Soil salinity (dS/m) |
| DS0 | 1:0 | 0 | 10.8w | 11.3q | 11.5w |
|      | 1:20 | 0 | 11.9n | 12.1l | 13.1c |
|      | 1:30 | 0 | 10.5y | 10.7x | 10.8w |
| | 1:0 | 0 | 11.6p | 11.9n | 12.6g |
|      | 1:20 | 0 | 10.0b | 10.2x | 10.4z |
|      | 1:30 | 0 | 11.2t | 11.6p | 11.9n |
| DS1 | 1:0 | 0 | 11.5q | 11.8o | 11.9n |
|      | 1:20 | 0 | 12.5b | 12.8e | 13.4b |
|      | 1:30 | 0 | 11.0v | 11.3s | 11.4r |
|      | 1:0 | 0 | 12.0m | 12.2k | 12.7f |
|      | 1:20 | 0 | 10.5y | 10.8w | 10.8w |
|      | 1:30 | 0 | 11.5q | 11.8o | 11.9n |

Data with similar letters are not significant (P < 0.05), D0 and D1 are normal and intensive drought stress, respectively.
nitrogen fixation and thereby increase the plant growth of the main crop (corn) and improve the plant resistance to abiotic stress such as heavy metals that is similar to our results. However, they did not consider the interaction effects of other abiotic stresses such as salinity and drought [39]. Increasing the plant growth in the intercropping system has been mentioned by different researchers [30, 40]. The results of Hamzei et al. (2015) showed that chickpea-barley intercropping improved all canopy growth indices in comparison to sole cropping that is in line of our results [40].

The greatest plant Cd (Table 7) and Pb (Table 8) concentration was measured in the corn cultivated in the intercropping system under normal conditions, while the lowest belonged to the corn in monoculture system under drought stress.

Regardless of salinity and drought stress, corn cultivation in the intercropping system significantly increased the Pb and Cd concentration. The results of our studies showed that corn cultivation in the intercropping system significantly increased the Pb concentration under normal, salinity, and drought stress by 15.3, 12.5, and 13.2%, respectively. For plant Cd concentration, it was increased by 13.1, 8.3, and 11.9%, respectively which can be attributed to the role of intercrop plant in increasing the growth of main plant and thereby enhancing the heavy metal uptake by corn.

However, plant abiotic stresses had negative effects on heavy metal uptake by plants or biodegradation of diesel oil in the soil that is a negative point in environmental studies is in line with our results. Accordingly, the present research showed that corn cultivation in monoculture relative to intercropping system significantly decreased the plant Pb and Cd concentration by 12.2 and 10.8 % under salinity and drought stress, respectively. For biodegradation of diesel oil in the soil, it was decreased by 14.2 and 11.7% indicating the more negative role of salinity than drought stress on heavy metal uptake or biodegradation of petroleum hydrocarbon in the soil. Generally, soil salinity can increase the solubility of heavy metals in the soil that has toxic effects on soil microorganism or plant growth and thereby decrease the biodegradation of heavy metals in the soil [41]. The remarkable point of this research is that increasing the ratio of corn to white clover can moderate the negative effects of drought or salinity stress on the sorption of heavy metals or the biodegradation of petroleum hydrocarbon in the soil.

### Table 5: Effect of corn and white clover intercropping, soil salinity, drought stress, and diesel oil on POX enzyme activity (Unit/mg protein)

| Drought stress | Corn to white clover ratio | Diesel oil (% W/W) | P.indica (+) | P.indica (-) |
|----------------|----------------------------|--------------------|--------------|--------------|
|                |                            |                    | Initial salinity | Initial salinity |
|                |                            |                    | 6              | 6              |
| D0            | 1:0                        | 0                  | 12.2s*        | 12.7o        |
|                | 1:20                       | 0                  | 13.4j        | 13.7g        |
|                | 1:30                       | 0                  | 11.5x        | 11.8v        |
| D1            | 1:0                        | 0                  | 12.0t        | 13.1n        |
|                | 1:20                       | 0                  | 13.1n        | 13.3k        |
|                | 1:30                       | 0                  | 11.5x        | 11.8v        |

*Data with similar letters are not significant (P < 0.05), D0 and D1 are normal and intensive drought stress, respectively.

### Table 6: Effect of corn and white clover intercropping, soil salinity, drought stress, and diesel oil on plant biomass (g)

| Drought stress | Corn to white clover ratio | Diesel oil (% W/W) | P.indica (+) | P.indica (-) |
|----------------|----------------------------|--------------------|--------------|--------------|
|                |                            |                    | Initial salinity | Initial salinity |
|                |                            |                    | 6              | 6              |
| D0            | 1:0                        | 0                  | 4.35x         | 4.45x         |
|                | 1:20                       | 0                  | 4.60x         | 4.51o         |
|                | 1:30                       | 0                  | 4.71d         | 4.65j         |
| D1            | 1:0                        | 0                  | 4.65g         | 4.61i         |
|                | 1:20                       | 0                  | 4.65j         | 4.61i         |
|                | 1:30                       | 0                  | 4.72c         | 4.67f         |

*Data with similar letters are not significant (P < 0.05), D0 and D1 are normal and intensive drought stress, respectively.
4. Conclusion

Based on the results of this study, plant inoculation with *P. indica* had a significant effect on increasing biodegradation percentage of diesel oil in the soil which can be related to the positive role of *P. indica* fungus on increasing the plant biomass and may increase the plant root exudate which is an important carbon source for soil microbial activates. Therefore, increasing soil microbial activities can increase the biodegradation percentage of diesel oil in the soil. However, salinity and drought stress had an adverse effect on decreasing the diesel oil biodegradation in the soil. Increasing the soil salinity from the initial level (for control soil) to 6 dS/m significantly increased the APX and POX enzyme activities which indicate that plants can resist to plant abiotic stress via increasing the plant enzyme activities. In addition, the corn intercropping system had significant effect on increasing the diesel oil biodegradation in the soil. However, the plant physiology of the main crop, intercrop plant type, and soil physic-chemical properties have different effect on diesel oil biodegradation in the soil which should be considered in different studies.

Authors’ Contributions

Amir Hossein Baghaie: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Supervision; Writing-original draft; Writing-review and Editing.

Conflicts of Interest

The Authors declare that there is no conflict of interest.

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References

1. Zamora Ledezma C, Negrete Bolagay D, Figueroa F, Zamora Ledezma E, Ni M, Alexis F, et al. Heavy Metal Water Pollution: A Fresh Look about Hazards, Novel and Conventional Remediation Methods. *Environ Technol Innovat.* 2021: 101504.
2. Rahaman MAT, Paul M, Bhoumik N, Hassan M, Alam MK, Aktar Z. Heavy Metal Pollution Assessment in the Groundwater of the Meghna Ghat Industrial Area, Bangladesh, by Using Water Pollution Indices Approach. *Appl Water Sci* 2020; 10(8): 1-5.

3. Qin G, Niu Z, Yu J, Li Z, Ma JY, Xiang P. Soil Heavy Metal Pollution and Food Safety in China: Effects, Sources and Removing Technology. *Chemosphere*. 2020: 129205.

4. Kumar V, Sharma A, Kumar R, Bhardwaj R, Kumar Thukral A, Rodrigo-Comino J. Assessment of Heavy Metal Pollution in Three Different Indian Water Bodies by Combination of Multivariate Analysis and Water Pollution Indices. *Human Ecol Risk Assess: An Int J* 2020; 26(1): 1-6.

5. Jia X, Fu T, Hu B, Shi Z, Zhou L, Zhu Y. Identification of the Potential Risk Areas for Soil Heavy Metal Pollution Based on the Source-sink Theory. *J Hazard Mater*. 2020; 393:122424.

6. Liu K, Li C, Tang S, Shang G, Yu F, Li Y. Heavy Metal Concentration, Potential Ecological Risk Assessment and Enzyme Activity in Soils Affected by a Lead-zinc Tailing Spill in Guangxi, China. *Chemosphere*. 2020; 251: 126415.

7. Wang Q, Hao D, Li F, Guan X, Chen P. Development of a New Framework to Identify Pathways from Socioeconomic Development to Environmental Pollution. *J Clean Prod*. 2020; 253: 119962.

8. Hu B, Shao S, Ni H, Fu Z, Hu L, Zhou Y, et al. Current Status, Spatial Features, Health Risks, and Potential Driving Factors of Soil Heavy Metal Pollution in China at Province Level. *Environ Pollut*. 2020; 266: 114961.

9. Adimalla N, Chen J, Qian H. Spatial Characteristics of Heavy Metal Contamination and Potential Human Health Risk Assessment of Urban Soils: A Case Study from an Urban Region of South India. *Ecotox Environ Saf*. 2020; 192: 114046.

10. Nistášescu V, Mittelau M, Gounenou M, Docea AO, Renieri E, Udéanu DI, et al. Heavy Metal and Pesticide Levels in Dairy Products: Evaluation of Human Health Risk. *Food Chem Toxicol*. 2020; 146: 111844.

11. Otunola BO, Ololade OO. A Review on the Application of Clay Minerals as Additional Carbon Source for Rhizosphere Microorganisms and Reduces Root Exudate Starch. *Sci Rep*. 2021; 11(1): 10856.

12. Liu S, Yang B, Liang Y, Xiao Y, Fang J. Prospect of Phytoremediation Combined with other Approaches for Remediation of Heavy Metal-Polluted Soils. *Environ Sci Pollut Res*. 2020; 27(14): 16069-85.

13. Wang S, Wei M, Cheng H, Wu B, Du D, Wang C. Indigenous Plant Species and Invasive Alien Species Tend to Diverge Functionally under Heavy Metal Pollution and Drought Stress. *Ecotox Environ Saf*. 2020; 205: 111160.

14. Mansoor S, Kour N, Manhas S, Zahid S, Wani OA, Sharma V, et al. Biochar as a Tool for Effective Management of Drought and Heavy Metal Toxicity. *Chemosphere*. 2020: 129458.

15. Moussavi Kouhi SM, Moudi M. Assessment of Phytoremediation Potential of Native Plant Species Naturally Growing in a Heavy Metal-polluted Saline-Sodic Soil. *Environ Sci Pollut Res*. 2020; 27(9): 10027-38.

16. Zaman J, Hajabbasi MA, Aliae E, Sepehr M, Leuchtmann A, Schulin R. The Effect of Phytoremediation on the Root Development of Maize (Zea mays L.) and Remediation of Petroleum Contaminated Soil. *Int J Phytoremediation*. 2016; 18(3): 278-87.

17. Baghaie AH, Jabari AG. Effect of Nano Fe-oxide and Endophytic Fungus (*P. indica*) on Petroleum Hydrocarbons Degradation in an Arsenic Contaminated Soil under Barley Cultivation. *J Environ Health Sci Eng*. 2019; 17(2): 853-61.

18. Bian F, Zhong Z, Li C, Zhang X, Gu L, Huang Z, et al. Intercropping Improves Heavy Metal Phytoremediation Efficiency through Changing Properties of Rhizosphere Soil in Bamboo Plantation. *J Hazard Mater*. 2021; 416: 125898.

19. Van Wijk MT. Understanding Plant Rooting Patterns in Semi-Arid Systems: an Integrated Model Analysis of Climate, Soil Type and Plant Biomass. *Global Ecol Biogeography*. 2011; 20(2): 331-42.

20. Mendez MO, Maier RM. Phytoremediation of Mine Tailings in Temperate and Arid Environments. *Review Environ Sci BioTechnol*. 2008; 7(1): 47-59.

21. Moubasher H, Hegazy A, Mohamed N, Moustafa Y, Kabil H, Hamad A. Phytoremediation of Soils Polluted with Crude Petroleum Oil Using Bacteria Scoparia and its Associated Rhizosphere Microorganisms. *Int Biodeterior Biodegradation*. 2015; 98: 113-20.

22. Besalatpour A, Hajabbasi M, Khoshsoltaninasseri A, Dorostkar V. Landfarming Process Effects on Biochemical Properties of Petroleum-contaminated Soils. *Soil Sed Contam*. 2011; 20(2): 234-48.

23. Irfan M, Ahmad A, Hayat S. Effect of Cadmium on the Growth and Antioxidant Enzymes in Two Varieties of Brassica Juncea. *Saud J Biol Sci*. 2014; 21(2): 125-31.

24. Gutiérrez-Martínez PB, Torres Morán ML, Romero Puertas MC, Casas Solís J, Zarazúa Villaseñor P, Sandoval Pinto E, et al. Assessment of Antioxidant Enzymes in Leaves and Roots of Phaseolus vulgaris Plants under Cadmium Stress. *Biotecnica*. 2020; 22(2): 110-8.

25. An L, Pan Y, Wang Z, Zhu C. Heavy Metal Absorption Status of Five Plant Species in Monoculture and Intercropping. *Plant Soil*. 2011; 345(1): 237-45.

26. Lange M, Eisenhauer N, Sierra CA, Bessler H, Engel S, Griffiths R, et al. Plant Diversity Increases Soil Microbial Activity and Soil Carbon Storage. *Nat Commun*. 2015; 6(1): 1-8.

27. Shi S, Richardson AE, O’Callaghan M, DeAngelis KM, Jones EE, Stewart A, et al. Effects of Selected Root Exudate Components on Soil Bacterial Communities. *FEMS Microbiol Ecol*. 2011; 77(3):600-10.

28. Mitter EK, Germida JJ, de Freitas JR. Impact of Diesel and Biodiesel Contamination on Soil Microbial Community Activity and Structure. *Sci Rep*. 2021; 11(1): 10856.

29. Baghaie AH, Ghafar Jabari A, Sattari R. The Effect of Corn and White Clover Intercropping on Biodegradation of Diesel Oil in Arsenic Contaminated Soil in the Presence of Phytosporina Indica. *J Human Environ Health Promot*. 2020; 6(2): 53-9.

30. Maarastawi SA, Fridtide K, Bodelier PL, Kieft C. Rice Straw Serves as an Additional Carbon Source for Rhizosphere Microorganisms and Reduces Root Exudate Consumption. *Soil Biol Biochem*. 2019; 135: 235-38.

31. Steinauer K, Chatzinotas A, Eisenhauer N. Root Exudate Cocktails: The Link between Plant Diversity and Soil Microorganisms. *Ecol Evolut*. 2016; 6(20): 7387-96.

32. Jin J, Wang M, Lu W, Zhang L, Jiang Q, Yin J, et al. Effect of Plants and Their Root Exudate on Bacterial Activities during Rhizobacterium-plant Remediation of Phenol from Water. *Environ Int*. 2019; 127: 114-24.

33. Su ZZ, Wang T, Shrivastava N, Chen YY, Liu X, Sun C, et al. Phytoremediation Indica Promotes Growth, Seed Yield and Quality of Brassica Napus L. *Microbiol Res*. 2017; 199: 29-39.

34. del Reguío Cabañas Mendoza M, Santamaría JM, Sauri Duch E, Escobedo-GarcíaMedrano RM, Andrade JL. Salinity Affects pH and Lead Availability in Two Mangrove Plant Species. *Environ Res Commun*. 2020; 2(6): 061004.

35. Khoshsoltaninasseri A, Shariatmadari H, Karimian N. Effects of Saline Irrigation Water and Zn Application on Soil Cd Solubility and Cd Concentration in Wheat. *J Water Soil Sci*. 2004; 7(4): 53-60.
36. Zhang S, Ni X, Arif M, Yuan Z, Li L, Li C. Salinity Influences Cd Accumulation and Distribution Characteristics in Two Contrasting Halophytes, Suaeda Glauc and Limonium Aureum. Ecotox Environ Safe. 2020; 191: 110230.

37. Filipović L, Romić M, Romić D, Filipović V, Ondrašek G. Organic Matter and Salinity Modify Cadmium Soil (Phyto) Availability. Ecotoxicol Environ Safe. 2018; 147: 824-31.

38. Minai Tehrani D, Herfatmanesh A, Azari Dehkhordi F, Minuoi S. Effect of Salinity on Biodegradation of Aliphatic Fractions of Crude Oil in Soil. Pak J Biol Sci. 2006; 9(8): 1531-5.

39. Li N, Li Z, Zhuang P, Zou B, McBride M. Cadmium Uptake from Soil by Maize with Intercrops. Water Air Soil Pollut. 2009; 199(1): 45-56.

40. Hamzei J, Seyedi M. Study of Canopy Growth Indices in Mono and Intercropping of Chickpea and Barley under Weed Competition. J Agr Sci Sustain Product. 2015; 24(4.1): 75-90.

41. Usman AR. Influence of NaCl-induced Salinity and Cd Toxicity on Respiration Activity and Cd Availability to Barley Plants in Farmyard Manure-amended Soil. Appl Environ Soil Sci. 2015; 2015: 1-8.