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Multi-system Phytoremediation on Oil-contaminated Chernozem Soil in Daqing Oilfield

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Abstract. Daqing oil-contaminated chernozem soil and high concentrations oil-pollutant samples were mixed at the ratio of 4:1, 2:1, 1:1 and 1:2(v_{soil}/v_{oil}), respectively. Then the oil content of the mixed samples were detected and analyzed after phytoremediation experiment with multi-plant systems. The research results showed that Maryland-Millet-Phlox-Parthenocissus-Thistle Herb-Lettuce multi-plant system had a good degradation effect on oil-pollutants. During the 105-day experiment, the degradation rate of oil-pollutants could be up to 68.5% in the mixed soil (4:1, v/v). During the whole experiment, removal rate of total petroleum hydrocarbons(TPHs) could reach 62.5% in the Motherwort-Asclepiadaceous-Zinnia-Artemisia sieversiana-Medicago-Artemisia ordosica multi-plant system mixed soil (2:1, v/v). Experimental results proved that the degradation effect on TPHs could be improved by the multi-plant systems and they could be reasonably matched to cure and restore the ecological environment of oil-contaminated soils.

Keywords: Daqing oilfield; oil-contaminated soil; chernozem; multi-plant system; phytoremediation

1. Introduction

Soil is a kind of indispensable and non-renewable resources. But soil contamination by petroleum hydrocarbons, a very important problem, has been attracting considerable public attention over the past decades[1]. Petroleum hydrocarbon contamination of soil occurs through extraction, accidents, transportation and leakage from tanks, pipeline ruptures, consumption and refining[2]. The oil-contaminated soil could cause organic pollution of local ground water, threaten the safety of drinking water, limit the use of ground water, produce enormous economic loss and ecological disaster and destroy agricultural production[3]. Therefore, phytoremediation, the use of plants for in situ treatment of environmental problems, has been recognized as a more cost-effective and social acceptable alternative[4,5]. Simultaneously, it is a low input approach by biodegradation and physiochemical that decrease the contaminant concentration where sowing plants may be the only intervention[6].

On the basis of the pre-pot experiment[7], the aim of this research was to investigate further the phytoremediation effects of multi-plant systems on total petroleum hydrocarbons(TPHs)[8]. TPHs are one of the most common groups of persistent organic contaminants in the environment and they are known to be toxic to many living organisms[9-11]. So, the phytodegradation of TPHs was determined gravimetrically.

Various plant species are different in their root characteristics and exudates compounds (as carbon source and biosurfactant), which influence microbial degradation, soil properties, and TPHs mobilization[12]. It implied that plant selection and collocation is an important parameter to optimize for the phytoremediation of oil-contaminated soil, because it can provide a more beneficial rhizosphere condition for improving biodegradation and bioavailability of pollutants[13]. Thus, more information about multi-system phytoremediation is urgently needed.

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2. Materials and methods

2.1. Soil sample collection and preparation

The chernozem, the typical soil of Daqing area was chosen as the test soil sample. The oil-contaminated soil which was regarded as crude oil pollutant was collected from the production area of first oilfield. The soil samples were broken to pass through a 24-mesh sieve. Some big particles and plants residues must be devised out of the soils. By mixed chernozem with oil-contaminated soil, the volume ratio (v_{soil}/v_{oil}) in the test soil was 4:1, 2:1, 1:1 and 1:2, as the treatment A, B, C and D, respectively. Soil samples (2000g dry weight per pot) with the same proportion should be prepared at the same time and mixed homogeneously. The soil samples were packed into experimental pots (15cm in diameter and 12cm in height), as the depth of soil in each pot was about 10cm. The cultured pots should be carefully labeled, and then located at a sunny place in laboratory.

2.2. Multi-plant systems selection

Totally, thirty plant species were screened for their potential of TPH removal. Moreover, several different species of plants were chosen for every pot-culture experiment. The collocations of multi-plant systems are shown as follows:

System 1-1: Motherwort-Asclepiadaceous-Zinnia-Artemisia sieversiana-Medicago-Artemisia ordosica (MAZAMA)

System 1-2: Setaira viridis-Raphanus sativus-Brassica rapa pekinensis-Iris tectorum-Marigold (SRBIM)

System 1-3: Dockleaf knotweed-Chenopodium album L-Giycine max-Amaranth-Pennisetum alopecuroides (DCGAP)

System 1-4: Maryland-Millet-Phlox-Parthenocissus-Thistle Herb-Lettuce (MMPPTL)

System 1-5: Dactylis glomerata-Amaranthus hypochondriacus-Coronilla varia (DAC)

System 1-6: Festuca arundinacea schreb-Lolium perenne-Sorghum hybrid sudangrass (FLS)

2.3. Sampling and analysis

During the experiment, the soil was collected at 0, 30, 60 and 105 days after the start of experiment, respectively. Soil samples in planted pot were collected from the rhizosphere area in the depth of 2~3cm with the shape of "crossing". The each sample is about 8 gram. The samples should be dried naturally in the shade, and they were ground to pass through a 0.25 mm sieve. Then impurities must be devised out of the soils. The TPHs in the soils were measured with the mass method and the calculation formula as follows:

$$TPH(mg/kg) = W \times 1000/M$$

Where, W—Weight of chloroform extracts (mg); M—Weight of the test soil (g).

3. Results and discussion

3.1. Phytoremediation efficiency-treatment A

Phytoremediation efficiency of multi-plant system under the treatment A(v_{soil}/v_{oil}=4:1) was shown in Fig. 1. On the whole, the remediation on the oil-contaminated soil with the soil-oil ratio is 4:1 was effective. The degradation got the highest speed in primary stage, and the speed will go down with the time, moreover, the degradation rate increased with the time increasing totally. During the 30-day culture period, the average removal efficiency of the TPHs in the soils was 46.93%. The degradation rate in the multi-plant system 1-1 and 1-4 was more than 60%, and evidently higher than that in 1-5 and 1-6 (less than 30%). After another 30 days, the average degradation was 61.6%. From the trends, it can be found that the degradation rate of multi-plant system 1-4 (MMPPTL) is highest(64.4%) in the six multi-plant experiment systems. The MMPPTL system could attain a higher degradation speed in short time, and got ahead of multi-plant system 1-1 after 60d's growth. In the multi-system 1-4, Phlox and Thistle grew well and appeared a good endurance to petroleum contaminants, roots proliferate sufficiently, and their luxuriant root system could help to remove the petroleum hydrocarbons. Generally speaking, the MMPPTL system was the most suitable one for treatment A(v_{soil}/v_{oil} =4:1).

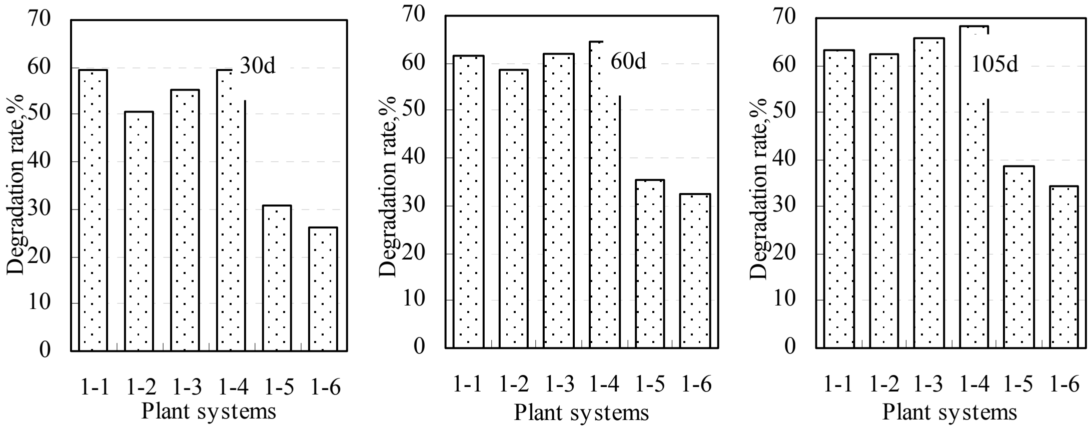

Fig. 1. Degradation rate of multi-plant systems after 30d, 60d and 105d under the treatment A(v_{soil}/v_{oil}=4:1)

3.2. Phytoremediation efficiency-treatment B

Phytoremediation efficiency of multi-plant system under the treatment B(v_{soil}/v_{oil}=2:1) was shown in Fig. 2. Obviously, some difference of TPHs degradation was observed between the treatments A and B. After 105 days, the average removal rate of the multi-systems was 41.82% in the experiments. System 1-1 (MAZAMA) exhibited the best remediation effects, the TPHs degradation rate was raised up to 62.55%, and another three kinds of multi-plant systems can also be achieved a higher degradation rate over 40% during the 105d experiment. In the oil-contaminated chernozem soil, the Motherwort, Zinnia and Medicago germinated and grew well in the experiment.

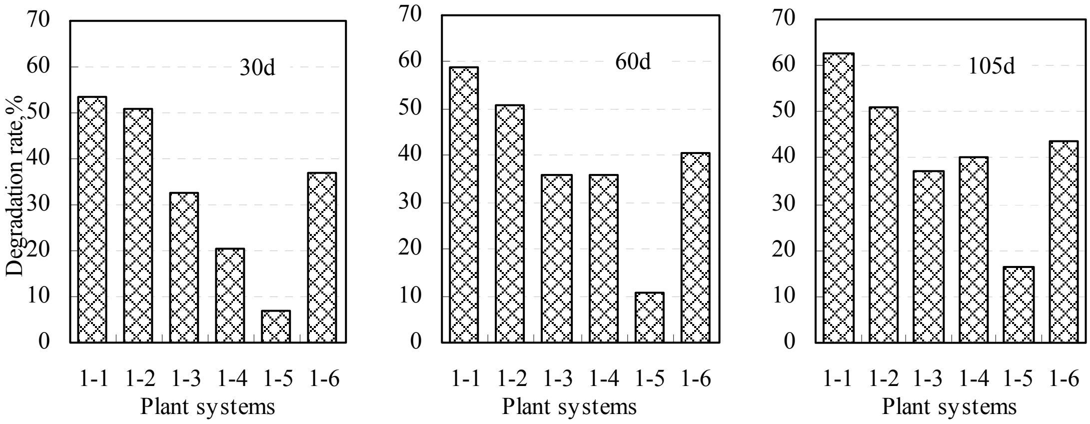

Fig. 2. Degradation rate of multi-plant systems after 30d, 60d and 105d under the treatment B(v_{soil}/v_{oil}=2:1)

3.3. Phytoremediation efficiency-treatment C

Fig. 3 shows the extent of TPHs degradation by the treatment C(v_{soil}/v_{oil}=1:1).

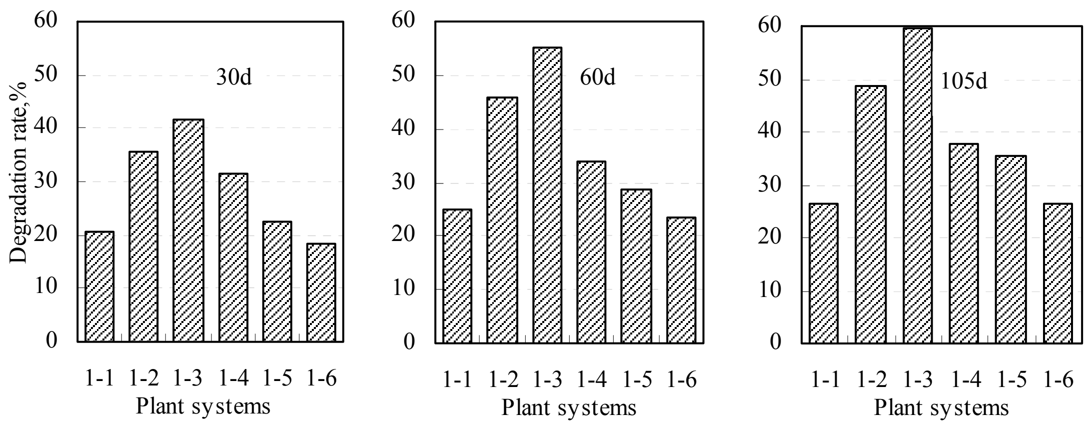

Fig. 3. Degradation rate of multi-plant systems after 30d, 60d and 105d under the treatment C(v_{soil}/v_{oil}=1:1)

As compared to the treatments of A and B, the removal efficiency of TPHs was significantly decreased which may be caused by the higher TPHs concentration had inhibitive effects during the plants growth. On average, the TPHs residue percentage was 71.7% after 30d experiment. System 1-3 was the most effective in all multi-plant systems under the treatment C, however, the degradation rate was only 41.5% in 30d experiment. In the following 75 days, the removal efficiencies of TPHs were significantly enhanced, but the trends of different multispecies cultivations didn't change a lot. Therefore, it is concluded that DCGAP system has the best performance under the treatment C.

3.4. Phytoremediation efficiency-treatment D

The change characteristics of degradation rate of multi-plant systems under treatment D(v_{soil}/v_{oil}=1:2) were depicted in Fig. 4. The results indicated that growth status of plants played an important role in the oily pollutant phytoremediation. It was observed that the high concentration of oily pollutant impacted plant growth compared with low concentration of oil treatments. By the end of the trail (105d), the average removal rate of TPHs was only 24.99%. The degradation degree was barely observed for multi-systems 1-4 and 1-5. Comparing the other systems, system 1-2 displayed the most significantly effectiveness, up to 42.46%. It implied that SRBIM system is one of most effective plant to promote TPHs losses among the six multi-plant systems under the treatment D.

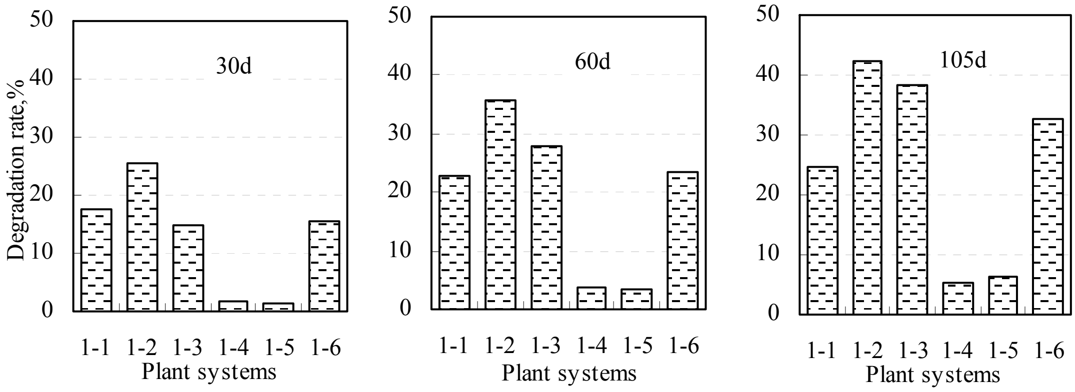

Fig. 4. Degradation rate of multi-plant systems after 30d, 60d and 105d under the treatment D(v_{soil}/v_{oil}=1:2)

4. Conclusion

In the experimental group of treatment A, the combination of Thistle and Phlox was most effective with a TPHs degradation rate of 68.5%. They grew well with highly branched fine fibrous root systems. At the early period, the degradation speed and remediation effects were better than that at the later period.

In addition, the experiment results indicated that MAZAMA system had best phytoremediation efficiency with a degradation rate of 62.5% in the experimental group of treatment B. Generally, the degradation effects of the experimental group were not as good as treatment A, which may be caused by the higher TPHs concentration.

Over the 105-day culture period, the phytoremediation efficiency of DCGAP system in treatment C was up to 59.4%, which was the best effects in the treatment experiments. And at later period, the degradation speed was still higher, which probably due to the plants adapt to degrading TPHs pollutants until the end of the period of bioremediation. Multi-plant system 1-5 (DAC) and 1-6 (FLS) exhibited similar results after 30 d experiment, got 22.3% and 18.4%, respectively.

In the experimental group of treatment D, multi-plant system 1-2 displayed a better promotion of TPHs dissipation and shown a higher degradation speed at the early and later period, as compared with the other systems. However, on the whole, the decomposition rate of SRBIM system exhibited a lower level than the other experimental treatment groups. Noticeably, system 1-4 (MMPPTL) didn't have combined remediation process at early period. Similar results can be found in system 1-5 and 1-6, which probably because of the higher toxicity of samples in the experimental group become inhibitive effects on the growth of plants.

The phytoremediation effect of multispecies cultivation could be influenced by the collocation of plants, planting time, oil-contaminated concentration and so on. In chernozem soil, the plants could effectively promote the degradation of TPHs pollutants under the lower oil-contaminants concentration. Meanwhile, multi-plant system requires some plants which are suitable for chernozem soil, just like Brassica rapa. A good remediation effects might be gained during a long enough period. Experiment results have demonstrated that the phytoremediation efficiency of the multi-plant systems was depended on the level of oily contaminants in soil. Therefore, remediation plants should be selected according the initial constitutes of contaminants concentration in the oil-contaminated soils.

5. Acknowledgments

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