Remediation of As-polluted Soils by Plant

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Abstract: Phytoremediation, the technology using plants to reduce or remove pollutants from environment, has the benefits of low cost and low environmental impact. *Pteris vittata* L. is well known as arsenic hyperaccumulating fern and expected as the strong candidate for application to phytoremediation. This fern has been used to remedy actual sites contaminated with arsenic. In this report, the outlines of our trial to apply *P. vittata* to phytoremediation are introduced.
Keywords: Arsenic, Phytoremediation, *Pteris vittata* L.

1. Introduction

The strong ability of *Pteris vittata* L., common name is the Chinese brake fern, to reduce or remove of arsenic from contaminated soils was reported by Ma et al. for the first time. Their experimental result showed that, *P. vittata* could accumulate arsenic with the extremely high concentration of 22,630 mg kg^{-1} DW in its plant body, of which cultivated in a arsenic added soils with the concentration of 1,500 mg As kg^{-1} using sodium nitrate. About this fern plant, they stated an expectation to be applied for the phytoremediation of arsenic, on the grounds for its high biomass production and versatile adaptability to the different cultural conditions.

In these six years, we, the author and associates, have applied this fern to treat the four sites contaminated with arsenic in Japan. To carry out a phytoremediation using *P. vittata* in practice, plant physiological and soil chemical knowledge concerning the arsenic hyperaccumulation are very important as the bases of a phytoremediation technology. Thus, we made a confirmation that the ability of *P. vittata* to remove arsenic from contaminated site, and then considered a classification analysis of arsenic in contaminated soils from the actual sites to qualitatively evaluate the effectiveness of a phytoremediation. It is very important to carry out a treatability test in the planning stage of any phytoremediation, in order to verify the applicability and the end-goal of remediation. A pot culture using the actual contaminated soils and the detailed classification analysis are two major components of our treatability test. This report shows that, the results of our research for the phytoremediation of arsenic and the instance of actual remediation site.

2. Confirmation of Arsenic Removal

Two soils with different contamination levels, as shown in Table 1, were used for the pot culture experiment. *P. vittata* seedlings, cultivated from spore for 6 months, were transplanted to contaminated soils. The shoots of ferns were harvested after 6 months from transplanting then analyzed.

During experimental period, the arsenic concentrations in shoots increased both of ferns grown in two different soils. Especially, in the case of the fern grown in the high contaminated soil, the arsenic concentration in the shoot had achieved 16,700 mg kg^{-1} DW of which was almost hundred times higher as compared with that of the fern grown in the low contaminated soil.

Table 1. Arsenic contamination levels of two soils for pot culture.

	Water Leaching	1mol L^{-1} HCl Extracted
Soil Sample	mg L^{-1}	mg kg^{-1}
Low contaminated	0.042	43.5
High contaminated	3.80	560

The 1 mol L^{-1} HCl extracted arsenic concentration in high contaminated soil was approximately ten times higher than the concentration in low contaminated soil, whereas the water soluble arsenic concentration was close to a hundred times higher. The availability of metals in soil is the important factor to influence or determine the accumulation levels of metals in a plant body as well as the contamination level of soils. A water solubility of arsenic could be considered as an index parameter both contamination level and availability, due to water soluble arsenic is readily available for fern uptake. For this experiment using the two soils with different contamination levels, the ratios of arsenic concentration in shoot to the water soluble arsenic concentration in soils are 440 for the high contaminated soil 407 for the low contaminated soils, respectively. The similarity of these two values as a bioaccumulation factor based on the level of water soluble arsenic indicates that *P. vittata* can accumulate arsenic with same effectiveness from soils with wide range of contamination (Table 2).

In the process of phytoremediation for toxic meals, it is difficult as the methodology to harvest a whole of plant body including a root. Thus, one of the ideal abilities of plant for a cleanup soil is a translocation of more metal from root to its avobeground parts which is easier harvestable. As the result of our hydroponic experiment with different arsenic feeding levels, *P. vittata* transferred more than 80% of arsenic to their shoots whereas growing in the wide range of arsenic concentration in a nutrient solution (Fig. 1).

Table 2. Arsenic concentrations in soils and plants.

			Low Contaminated	High Contaminated
Soil	A:	0.1mol L-1HCl Extractable mg kg^{-1}	43.5	560
	B:	Water soluble mg kg^{-1}	0.42	37.9
Plant	C:	Total As mg kg^{-1}	171	16700
	D:	Ratio （ C／B ）	407	441

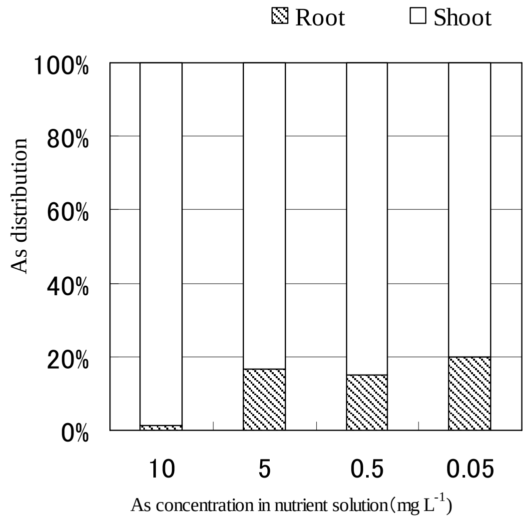

Fig 1. Arsenic distribution in plant with different arsenic feeding levels in hydroponics.

These experimental results about the arsenic removal by *P vittata* demonstrate the ideal abilities to remedy the contaminated sites, which are the applicability to wide range contamination and the translocation much of uptaken arsenic to its shoots.

3. Classification Analysis of Arsenic in Soil

The determination of the toxic metal removal by plants which grown in the actual contaminated site is the most direct way to evaluate the availability of the metal in soils. It must be rational and realistic to consider the phytoremediation plan, including the end-goal, based on the result of the first year trial. This way is direct and practical, but time-consuming procedure and difficult to extrapolate the result to the other site. Contrastively, the chemical soil analysis to evaluate an effectiveness of phytoremediation in the planning stage may be very useful as relatively rapid and comprehensive method.

Arsenic solubility and mobility in the environment are strongly influenced by chemical forms and associations with solid phases in soil. Therefore, a multi step extraction procedure with gradual change of extractants may provides useful information to estimate a effectiveness of arsenic removal by plant.

Under Japanese law, the Soil Contamination Countermeasure Act, there are two types of standards for soil pollution of which values are obtained through the water leaching test and the 1 mol L^{-1} HCl extraction. The regulatory criteria are important to make a remediation plan, thus we had considered multi step analysis based on these two types of soil test. To evaluate the arsenic availability, we choose the two anion exchangeable factions proposed by Keon et al. Then, the following five extraction methods were selected and placed as the classification analysis for the characterization of arsenic contamination in soils.

a) Water soluble arsenic: water leaching test
b) Cl exchangeable arsenic: 1 mol L^{-1} $MgCl_2$ extraction
c) PO4 exchangeable arsenic: 1 mol L^{-1} NaH_2PO_4 extraction
d) 1 mol L^{-1} HCl extractable arsenic
e) Acid digestion: concentrated HNO_3 and HCl with H_2O_2

Figure 2 shows instances of this classification analysis on the three actual contaminated soils. The arsenic concentrations in soil determined by acid digestion were 86.4 mg kg^{-1}, 481.3 mg kg^{-1} and 895.4 mg kg^{-1}, respectively. The arsenic distributions in the 1 mol L^{-1} HCl extractable arsenic concentrations were 40 to 60 % of values of acid digestion. Among the two types of anion exchangeable arsenic, the distributions of Cl exchangeable arsenic in soils were 1 to 5%, relatively low compared to the PO4 exchangeable arsenic of which strongly absorbed in solid phases of soil. The PO4 exchangeable arsenic accounted for 15 to 40% of arsenic in soils, corresponded to ten times larger pool size of Cl exchangeable.

It is assumed that the arsenic removal by *P. vittata* in the actual phytoremediation site may differ due to not only arsenic amount in soil but also arsenic distribution in each fraction. Furthermore, redistribution of arsenic in soil will make difficulty to evaluate the effectiveness of phytoremediation. In fact of our actual remediation sites, arsenic removal by plant often did not resulted in reducing the values examined through the water leaching test which was positioned as the Environmental Quality Standard for soil pollution under Japanese regulation.

The classification analysis described above, is carried out as one of the items in treatability test to make the characterization of arsenic contamination in soils and the qualitative information about effectiveness of arsenic removal by ferns.

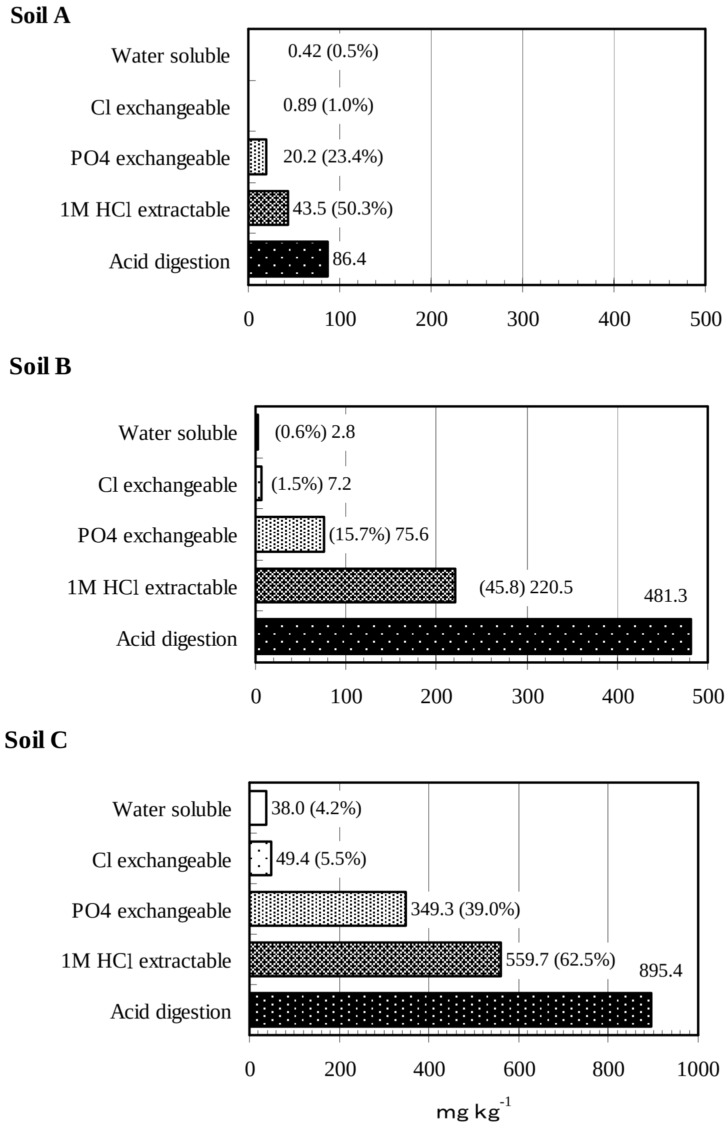

Fig 2. Results of classification analysis of As in contaminated soils Values in parentheses show percentage of acid digestion.

4. Instance of Phytoremediation to Arsenic Contaminated Site

As mentioned above, we had applied *P. vittata* to the arsenic phytoremediation of four actual contaminated sites. Here, I introduce the one of the remediation site of which application to 100 m^2 in an active chemical firm with fifth year trial at 2009.

The phytoremediation process which we used to propose to our customers is illustrated in Fig. 3. The view of remediation site and growing situation of ferns are as shown in Fig. 4, 5 respectively.

At the beginning of stage to make plan of phytoremediation, soils of contaminated site were subjected to the treatability test which consisted of the classification analysis of soils and pot culture experiment.

The seedlings of fern were grown on the cell tray with five to six months growing period. The soil of application field was tilled by using a cultivator before transplanting due to its hardness. Timer controlled irrigation system was installed in this site, the benefit of phytoremediation applied in the active firm that the utilities, tap water or power source, are available. The ferns start rapid growth after three months from transplanting, the weeds control is very

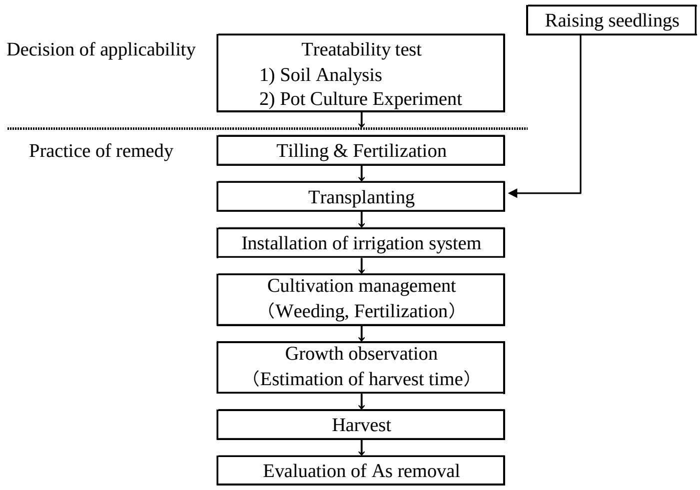

Fig. 3 Process of fhytoremediation used to propose.

important for this period. Therefore, we had demonstrated at some remediation sites that the selective herbicide application was effective to prevent overgrowth of weeds with very little influence on fern growth.

During cultivation period, the scheduled growth observations were carried out to decide the time of harvest that was used to set from mid-November to mid-December depending on the fern growth and climatic condition. As the result, arsenic removal of 43.5g from 100 m^2 was determined by the plant analysis in this phytoremediation site.

Fig 4. View of actual remediation site (Just after transplanting)

Fig 5. Growth of ferns (Left: 3 months from transplanting, Right: Just before harvest)

5. Conclusion

The hyperaccumulator fern (*Pteris vittata* L.) has been used to treat sites contaminated with arsenic. The phytoremediation is using plant technology to clean up a contaminated soil, then whole process of the method are close to agricultural procedures. Therefore, it is necessary to establish the steady efficiency for remedy that the repeated experiences of cultivation in actual field trials on the basis of the accumulated information in the area of plant physiology and soil chemistry.

References

[1] Ma, L.Q., Komar, K. M., Tu, C., Zhang, W. and Cai, Y., Kennelley, E. D., 2001. A fern that hyper accumulates arsenic, *Nature*, 409, 579.

[2] Keon, N. E., Swartz, C. H., Brabander, D. J., Harvey, C. and Hemond, H. S., 2001. Validation of an Arsenic Sequential Method for Evaluating Mobility in Sediments, Environmental Science & Technology, 35(13): 2778-2784.