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中国矿业大学优秀博士学位论文

矿区充填复垦 土壤重金属分布规律及 主要农作物污染评价

● 董霁红 著

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内 容 提 要

本书是中国矿业大学 2008 年优秀博士学位论文,是关于矿区充填复垦土壤重金属分布规律及主要农作物污染评价的研究专著。主要内容包括:国内外复垦场地研究现状综述,土壤、农作物中重金属分布规律研究趋势;土壤、植物样品的采集、处理与分析;充填复垦土壤特性实验研究;矿区复垦土壤重金属分布规律研究;复垦土壤特性与重金属分布的相关性研究;充填复垦区种植的主要农作物重金属污染现状及评价。

本书可供环境科学、环境工程、矿山土地污染与修复、矿山生态与恢复、土壤质量评价、农作物污染评价等相关领域的科研人员、工程技术人员、研究生和高年级本科生参考使用。

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前 言

矿区土壤重金属污染及其修复是当今矿山生态及我国区域性、行业性领域的研究热点,对土地可持续利用、粮食安全、矿区环境与区域生态保护具有重要意义。

本书通过对矿区充填复垦土壤进行系统、量化的野外及实验室研究,所得出的理论方法、数学模型、试验技术、相关数据、软件手段等可为国家指导矿区土地复垦和生态重建提供数据支持和科学指导,并可为相关矿区环境政策的制定提供参考。

本书在较系统地综述了国内外矿区复垦土壤研究进展情况的基础上,重点开展了五方面的研究工作:

1. 充填复垦土壤特性

场地实测与室内实验相结合,系统地研究了复垦土壤的理化、生物特性,包括土壤的渗透性、紧实度、孔隙水电导率、含水率、温度、pH 值、有机质、氮磷钾、重金属、微生物(细菌、真菌、放线菌)种类种数;选用美国 2800K1 型渗透仪、英国三参数速测仪 HH2/WET、美国紧实度仪 soil compaction,测试分析了土壤的紧实度等。数据结论:煤矸石、粉煤灰充填(覆土厚度 40 cm)复垦土壤的 pH 值为 7.98~8.78,含水率高于正常土壤 10%~20%,渗透性系数为 0.059~0.286,紧实度为 200~300 PSI,有机质含量低于对照土壤。这些研究结果对于国家制定矿区复垦技术标准及复垦工程的设计实施具有重要的参考价值。

2. 复垦土壤重金属分布规律

研究了矿区充填复垦土壤重金属污染问题,首先探讨了充填复垦区域土壤重金属空间分布特征分析的理论与方法,通过采集、处理、测试 245 个土样的 As、Cd、Cr、Cu、Hg、Pb、Zn 等的含量,利

用变化度、污染度和含量趋势等指标,解析研究了煤矸石充填复垦土壤、粉煤灰充填复垦土壤、对照土壤三类土壤的重金属分布特征;在此基础上,总结了七种元素的空间分布情况,对严重污染的Cd、轻度污染的Cr、正常范围的Pb进行了重点分析;采用线性、对数、指数、乘幂、多项式、Kriging阐释了Cd、Cr及Pb的空间分布规律,得出结论:①简单模型:拟合的模型在一定程度上能反映出微量元素的变化趋势,三块场地模型拟合的误差均值保持在30%以内,其中,煤矸石场地误差最小,最大值为18.4%,最小值为8.3%;②多项式模型:由反演所得数据绘制的模拟迁移图具有现实应用意义,即可利用模型由测点的数值推知未测点的数值,得到相对连续的重金属含量值,分析其空间分布规律;③Kriging模型:以粉煤灰场地的Cd为例,建立的模型拟合精度较高。上述研究结果将为矿区污染土地的修复并进而制定相应治理措施提供依据。

3. 土壤特性与重金属污染相关性的方法与理论

首先确定了可能影响土壤重金属分布的四个重要土壤特性:土壤紧实度、土壤pH值、土壤有机质以及土壤微生物;采用Pearson Correlation Coefficient方法,分析了pH值对重金属分布的影响、有机质与重金属分布的相关程度、紧实度与重金属污染的关系、微生物与重金属污染的相关性,结果表明:①充填复垦场地的pH值、有机质和紧实度与重金属含量的相关性较弱,相关系数都在-0.6~0.6之间,这也说明了在一定程度上,重金属空间分布的无规律性;②微生物与土壤重金属的相关性很大,在粉煤灰场地体现得更加明显,微生物的多少对土壤重金属含量产生直接的影响;最后应用集对理论(Set Pair Analysis Theory)研究了微生物与重金属的关联机理。这对于深入认识土壤重金属迁移机理的复杂性具有重要的科学意义,并可为其中难以定量和难以鉴别的污染相关因素的后续研究提供数据支持。

4. 主要农作物重金属污染物迁移规律研究

比较研究了世界主要国家和地区对小麦、水稻和大豆中重金属污染物的限量标准,提出了小麦等主要农作物重金属污染物限量的选取标准;采用单项、综合污染指数分析了根际土壤 As、Cd、Cr、Cu、Hg、Pb、Zn 的污染状况,得出了复垦土壤综合污染指数小于 1,全部测点均达到了土壤环境质量二级标准要求;定量解析了小麦不同部位的重金属含量,确定 Cd、Cr 为污染元素,研究结果:① 复垦场地生长的成熟小麦,Cd、Cr 在其不同器官中的分布迁移趋势是一致的;② 对照场地生长的成熟小麦,Cd、Cr 在其不同器官中的分布趋势存在差异;提出根富集系数率,进行曲线估计,建立了 Cd 回归方程、Cr 偏微分方程。这些研究结果对矿区粮食安全的监控具有重要的实际应用价值。

5. 土壤、作物污染程度的可视化表达

探索性地引入 Surfer 软件成图方法,借助多项式模型反演所得的数据,对矿区复垦土壤的结构进行可视化,直观地描述了土壤重金属分布的纵向、横向特征;应用 Photoshop 软件对小麦中重金属的污染迁移(以 Cd、Cr 为例)制作了量化模拟色彩映射图,真实地评价了小麦不同器官中重金属的污染程度。

董霁红

2008 年 9 月 11 日

Abstract

The study on soil heavy metals pollution and its rehabilitation in mining area is the present focus on mine ecology or the territorial and industrial fields in China. It is of great importance to sustainable land use, food security, mining area environment, regional environment protection and so on. After the systematic, quantitative field or laboratorial research of the filling reclamation soil in mining area, theoretical method, mathematical model, experimental techniques, relevant data, software measure and some other achievements were made. They offered the data support and scientific guidance for the state to supervise the land reclamation and ecological construction in mining area, also offered the reference for making related environment policy of mining area.

Systematically summarizing the research at home and abroad on reclamation soil in mining area, this paper focuses on the following five research works:

1. Research on filling reclamation soil characteristics

Reclamation site observation combined with indoor experiment, the physical, chemical and biological characteristics of filling reclamation soil have been systematically studied, concretely including the permeability, compaction, pore-water conductivity, water content, temperature, pH value, organic materials, nitrogen-phosphorus-kalium, heavy metals, microorganism (bacteria, fungi and actinomycetes) species or kinds; Soil compaction has been tested and analyzed using the 2800K1 Guelph—permeability testing machine made in USA, W. E. T Sensor Kit—the British three-parameter rapid measure instrument HH2/WET, the American compactness meter.

The data conclusions includes: the pH of both the coal-fly-ash and coal-gangue filling reclamation soil (cover soil thickness is 40 cm) is between 7.98 and 8.78; the soil water content is 10%~20% higher than natural soil; the permeability coefficient varies from 0.059 to 0.286; the soil compaction is between 200 PSI to 300 PSI; organic material content is lower than natural soil. To sum up, the index values of filling reclamation soil's physical and chemical properties are within the normal area of natural soil, and have no obvious difference. These results have significant reference value for the State to make land reclamation technical standards and to design and implement the reclamation project.

2. Research on the distribution of reclamation soil heavy metals

The problems about filling reclamation soil heavy metal pollution in mining area were brought forward. Firstly, the research went on the theories and methods used for analyzing heavy metal's spatial distribution characteristics in filling reclamation area. Two hundreds and forty five soil samples were collected and processed, and then the heavy metal concentrations of the soil samples, such as As, Cd, Cr, Cu, Hg, Pb, Zn and so on were determined. Three kinds of the soil heavy metals, coal-gangue filling reclamation soil, coal-fly-ash filling reclamation soil and natural soil were compared, the author analyzed and studied their distributions by varying multiple, contamination degree and concentration trends. The distributions of seven elements were summarized, and Cd arisen severe pollution, together with Cr arisen slight pollution and Pb in normal were emphatically analyzed. Expounding the spatial distributions of Cd, Cr and Pb by linearity, logarithm, index, power, polynomial, Kriging and other mathematical models, conclusions

were made as follows: ① Simple model: to a certain degree, the fitting model can figure out the change tendency of microelements, all the grand means of model fit errors of the three sites within 30%. The site error of coal gangue was the least, and the maximum is 18.4% while the minimum is 8.3%. ② Polynomial model: Making the analog transition diagram by the data inversion has practical meaning. The numerical value of unmeasured points can be deduced from measured points using models, and then gained the correspondingly seriate heavy metal contents, the spatial distributions can be analyzed. ③ Kriging model: The built models have high fitting precision, taking Cd of coal-fly-ash site as an example. The above research results will provide foundations for rehabilitating the polluted land in mining area and then setting corresponding government measures.

3. Methods and theories about the relativity between soil characteristic and heavy metal pollution

The four important specialties which effect soil heavy metals distributions were ascertained first: soil compaction, pH of soil, soil organic materials as well as soil microorganisms; employing in the Pearson Correlation Coefficient method, how pH affects the distribution of heavy metal, the correlation degree between organic material and the distribution of heavy metal, the relationships between compaction and heavy metal pollution, along with the relevancy between microorganism and heavy metal pollution were analyzed; The data results show that: ① The soil pH, soil organic matter and soil compaction of the filling reclamation site all only have slight correlation with heavy metals, and relativity coefficient is between -0.6 and 0.6 . To a certain extent, this also account for the irregularity of the spatial distribution of heavy metals. ② Soil microorganisms have high

correlation with soil heavy metals, and this presents much more obvious for a coal-fly-ash site. The quantity of microorganisms has a direct effect on the heavy metal content of soil. Finally, the relationship mechanism between microorganisms and heavy metals was studied by the application of Set Pair Analysis Theory. This has scientific significance for in-depth understanding the complexity of soil heavy metals' migration mechanism, and also can afford definite data support for the further study on the factors related to pollution which is difficult to quantify or distinguish.

4. Research on heavy metal pollution migration of main crops

Investigating and comparing the Limit Standard of the heavy metal contaminations in wheat, rice and soybeans in primary countries and regions in the world, we proposed the selection standards of the heavy metal contaminations quota in wheat and other main crops. The rhizospheric soil's pollution situations of As, Cd, Cr, Cu, Hg, Pb and Zn were analyzed by single contamination index method, also comprehensive contamination index method. It is concluded that comprehensive contamination index of reclamation soil was less than 1, and all the observation points reached to the secondary standard requirements of soil environment quality. The heavy metal contents of wheat's different parts were quantitatively analyzed, and Cd and Cr as contaminations were confirmed. The followings are the research results: ① The distributions and migration tendencies of each different parts of the mature wheat growing on reclamation sites consistent. ② There are differences in the distributions and migration tendencies of each different parts of the mature wheat growing on control sites. Root enrichment coefficient ratio was

put forward, and curve estimation was done, and Cd regression equation and Cr partial differential equation were established. These research results are provided with important practical value to monitor the food security in mining area.

5. Introduction of the description technique with the software of Surfer and Photoshop

Introducing the software Surfer to produce map, and using refutations data from polynomial model, we visualize the reclaimed soil structure of mining area, and intuitively described the vertical and horizontal distribution features of heavy metals in the soil; using the software Photoshop, taking Cd and Cr for example, we produced a quantitative simulation of color mapping maps to describe the migration of heavy metal pollution in the main crop wheat, and obtained a reliable evaluation of the heavy metals pollution levels in different organs of wheat.

目 录

1 绪论	1
1.1 研究背景	1
1.1.1 复垦场地研究现状综述	1
1.1.2 国内外复垦场地利用模式比较	3
1.1.3 矿区复垦场地重金属污染概述	4
1.1.4 国内外土壤重金属分布、迁移规律研究趋势	9
1.1.5 国内外主要农作物重金属污染研究进展	13
1.2 选题依据及研究意义	18
1.2.1 选题依据	18
1.2.2 研究意义	20
1.3 研究的内容、方法及技术路线	21
1.3.1 研究内容	21
1.3.2 研究方法	22
1.3.3 研究路线	23
2 研究区概况及样品的采集、处理与分析	24
2.1 基本概况	24
2.1.1 地理位置	24
2.1.2 气候条件	24
2.1.3 复垦场地状况	26
2.1.4 复垦充填物料	26
2.2 实验样区及样点剖面	27
2.2.1 样区位置	27
2.2.2 样点剖面结构	30

2.3	实验样区土壤状况	31
2.3.1	表层土	31
2.3.2	颗粒分级	31
2.3.3	矿物组成	34
2.4	土样的采集、处理	38
2.4.1	采样点的选择	38
2.4.2	土样的制备	40
2.5	植物样的采集、处理	42
2.5.1	采样点的确定	42
2.5.2	植物样的制备	42
2.6	数据分析的标准	44
2.7	本章小结	45
3	充填复垦土壤特性实验研究	47
3.1	场地试验、实验室实验	47
3.1.1	测定项目	47
3.1.2	测定方法	48
3.2	结果分析	49
3.2.1	土壤含水率、电导率、温度	49
3.2.2	土壤 pH 值	52
3.2.3	土壤紧实度	59
3.2.4	土壤渗透性	66
3.2.5	土壤有机质	71
3.2.6	土壤微生物	73
3.3	本章小结	75
4	矿区复垦土壤重金属分布规律研究	78
4.1	概述	79

4.1.1	问题的提出	79
4.1.2	土壤重金属的存在形态及主要污染物	80
4.2	复垦土壤(煤矸石)重金属分布特征	82
4.2.1	煤矸石(Gangue)中重金属的赋存	82
4.2.2	重金属含量随深度的变化	83
4.2.3	变化度与污染度	85
4.2.4	机理分析	89
4.3	复垦土壤(粉煤灰)重金属分布特征	92
4.3.1	粉煤灰(Fly Ash)与重金属迁移	92
4.3.2	重金属含量随深度的变化	93
4.3.3	富集度与污染度	95
4.3.4	解释分析	98
4.4	自然土壤(对照)重金属分布规律	99
4.4.1	重金属分布规律	99
4.4.2	变化度	101
4.5	三类土壤重金属污染现状	104
4.5.1	三类土壤重金属分布情况	104
4.5.2	7种元素分布情况表	106
4.5.3	优先污染元素的确定	107
4.6	Cd、Cr、Pb 污染评价	108
4.6.1	严重污染 Cd	108
4.6.2	轻度污染 Cr	113
4.6.3	正常范围 Pb	117
4.6.4	Cd、Cr、Pb 危害性分析	119
4.7	Cd、Cr、Pb 空间分布模型	121
4.7.1	简单拟合模型	121
4.7.2	多项式反演 Cd 可视化	126
4.7.3	多项式模型的现实意义	128

4.7.4	克里格插值模型	128
4.8	本章小结	135
5	复垦土壤特性与重金属分布的相关性研究	137
5.1	Pearson Correlation Coefficient(PCC)方法	137
5.1.1	PCC 方法的适用性	137
5.1.2	相关系数 r	138
5.2	土壤特性与重金属分布相关程度的定量分析	139
5.2.1	粉煤灰场地	139
5.2.2	煤矸石场地	142
5.2.3	对照场地	145
5.3	三场地 Pearson 相关性对比研究	147
5.4	同异反灰色相关分析法	153
5.4.1	同异反灰色相关分析法的背景	153
5.4.2	同异反灰色相关分析法的原理	154
5.4.3	同异反灰色相关分析法的应用	157
5.5	本章小结	159
6	充填复垦区种植的主要农作物重金属污染现状及评价	161
6.1	几种粮食作物重金属含量标准的讨论	161
6.2	标准选用	163
6.3	实验数据	164
6.4	根际土壤重金属污染现状及评价	169
6.4.1	根际土壤重金属含量分析	169
6.4.2	污染指数	170
6.4.3	重金属之间相关性分析	172
6.5	主要农作物重金属污染现状及评价——以小麦 为例	174

目 录

6.5.1 籽粒重金属含量分析	174
6.5.2 茎秆重金属含量分析	175
6.5.3 根系重金属含量分析	176
6.6 污染元素 Cr、Cd 的分布及迁移	177
6.6.1 Cd、Cr 在成熟小麦不同器官的分布	177
6.6.2 Photoshop 模拟色彩映射图	179
6.6.3 Cd、Cr 的富集系数及回归方程	184
6.6.4 Cr 偏微分方程的建立	189
6.7 本章小结	191
 7 主要结论与研究展望	 193
7.1 结论与建议	193
7.1.1 结论	193
7.1.2 相关建议	197
7.2 创新点	199
7.3 不足与展望	199
 参考文献	 200

Contents

1 Introduction	1
1.1 Research Background	1
1.1.1 Review of Present Research on Reclamation Site	1
1.1.2 Comparison of Utilization Mode of Reclamation Site at Home and Abroad	3
1.1.3 Research on Heavy Metal Pollution of Reclamation Site in Mining Areas	4
1.1.4 Research Trend in Distribution and Migration of Heavy Metals in Soils at Home and Abroad	9
1.1.5 Research Trend in Heavy Metal Pollution in Crops at Home and Abroad	13
1.2 Topic Selection Background and Research Significance	18
1.2.1 Topic Selection Background	18
1.2.2 Research Significance	20
1.3 Research Contents, Approach and Technique Course	21
1.3.1 Research Contents	21
1.3.2 Research Approach	22
1.3.3 Technique Course	23
2 General Situation of Research Areas and Soil Samples Collection, Processing and Analysis	24
2.1 General Situation	24
2.1.1 Geographical Position	24