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# 镍矿区周边不同距离玉米农田的重金属污染及转移规律

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**摘　要**：以吉林省镍矿区作为污染中心,调查周边1～5 km不同距离玉米农田中铬、镍、镉、砷和铅共5种重金属的含量及其在玉米体内的蓄积量和分配规律,为合理评价重金属污染状况及制定治理措施提供借鉴和参考。结果表明,镍矿区周边不同距离农田中,镍、镉含量超标1.3至8.9倍,砷含量接近标准上限,铬、铅不超标;在漂移性方面,镍和镉较弱,而砷、铬和铅较强。重金属含量高的农田,玉米子粒生物量呈显著下降趋势,降幅可达15.8%～31.7%。玉米对镍、铬和砷的富集量较多,对镉和铅的富集量较少,且倾向于砷、铬富集于子粒,镍、镉、铅富集于营养器官。吉林省镍矿区周边不同距离农田重金属污染和转移规律存在显著差异,玉米适合做镍的修复植物,在砷或铬含量高地区不宜种植食用玉米。

**关键词**：玉米;重金属;镍矿区;不同距离
**中图分类号**：S513.01　**文献标识码**：A

# Pollution and Transfer Regular of Heavy Metals in Maize Fields at Different Distances around Nickel Mining Areas

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**Abstract**: To find out heavy metal content in soil and its transfer regularity in crops in farmlands around different distance from the mining area , the nickel mining area in Jilin province was chosen as a center of pollution, investigated five heavy metals content including chromium, nickel, cadmium, arsenic and lead totally, and its absorption and distribution characters in maize field around different distance from 1 to 5 km, provided reference and reference on evaluation of heavy metal pollution and formulation of control measures. The results showed that, the contents of nickel and cadmium were 1.3 to 8.9 times higher than the standard, arsenic content was close to the upper limit, and chromium and lead were not higher than the standard in the fields around the nickel mine. In terms of mobility of heavy metals, nickel and cadmium were weaker, but arsenic, chromium and lead were stronger. The seed yield of maize showed a significant downward trend in the field with high content of heavy metals, with a decrease of 15.8% to 31.7%. The enrichment of Ni, Cr and As was higher in maize, while the enrichment of Cd and Pb was lower, and the enrichment of As and Cr in maize tended to be in the grain, while the enrichment of Ni, Cd and Pb in vegetative organs. In conclusion, there are significant differences in the pattern of heavy metal pollution and transfer in different distances around nickel mining areas in Jilin province, and maize is suitable to be used as nickel remediation plant, but is not suitable to plant maize in high arsenic or chromium content field.

**Key words**: Maize; Heavy metal; Nickel minging area; Different distance

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随着中国工业化的推进,土壤重金属污染问题日益严重。吉林省作为中国重要的粮食生产基地,农田土壤的重金属污染状况也受到了广泛关注。农田土壤中的重金属含量过高,不仅会影响农作物的生长,还会因为蓄积效应,最终危害人体健康[1~4]。有研究表明[5,6],吉林省大部分地区的农田土壤重金属污染状况并不严重,在污染分级上属于"清洁"一级,但在一些矿区周边,农田土壤的重金属含量仍超标严重[7,8]。

在土壤重金属的修复方法方面,有传统的原位土壤洗净法等工程式修复手段,需要耗费大量人力物力,在一些地区推广难度较大。通过种植特定植物修复污染土壤的生物技术手段更容易被人接受[9~12],考虑玉米种植业和深加工领域的产业优势及玉米本身具有的生物量大、可用于生产工业乙醇等特点[13~15],玉米被认为是适合吉林省的修复植物。相关研究[16~21]指出,利用生物能源类的植物对重金属污染土壤进行修复和利用,具有广阔的发展前景。目前,有研究调查吉林省矿区周边重金属的形态、含量及在作物中的分配规律,在距污染中心不同距离的重金属污染状况及影响等方面鲜有报道。本研究以吉林省镍矿区为中心,调查周边不同距离玉米农田土壤的重金属含量及其在玉米中的分配规律,为有效治理土壤重金属污染问题提供借鉴和参考。

# 1 材料与方法

## 1.1 试验设计

在玉米成熟期,以位于吉林省磐石市红旗岭镇的镍矿区为中心点,调查周边1~5 km不同距离的玉米农田的土壤及玉米植株内不同器官的重金属含量,分析重金属污染状况及转移规律。我国非蔬菜类食用农产品产地的土壤重金属含量限值见表1。

**表1 非蔬菜类食用农产品产地的土壤重金属含量限值**

Table 1 Limits for heavy metal content in soils of non-vegetable edible agricultural products mg/kg

| 项 目 Project | pH值 pH value | 铬 Cr | 镍 Ni | 镉 Cd | 砷 As | 铅 Pb |
|---|---|---|---|---|---|---|
| 土壤 | 6.5<pH<7.5 | 300 | 50 | 0.3 | 30 | 80 |

## 1.2 测定项目与方法

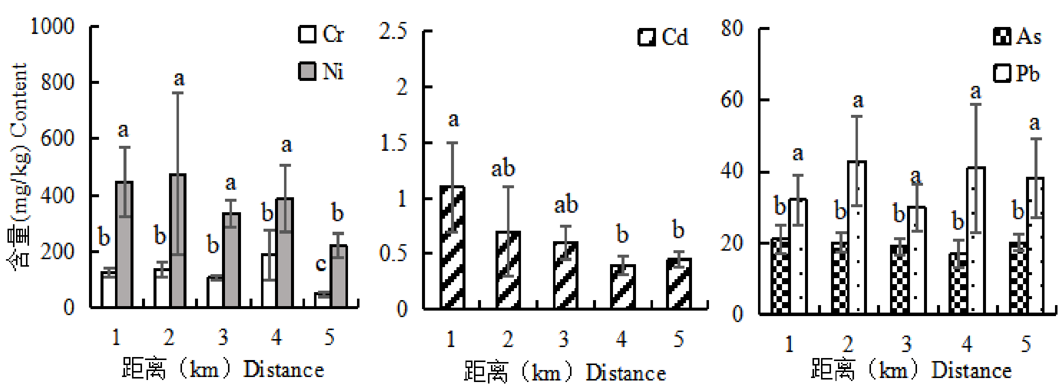
在每个距离选择3块不同的玉米农田,每块玉米农田随机采集15 $m^2$玉米及0~20 cm深的根际土壤。玉米按茎(含苞叶)、叶、芯和子粒分解,自然风干后,称取生物量,再用粉碎机磨碎,混合均匀。土壤在烘干后,磨碎混匀。用浓$HNO_3$和$H_2O_2$(hot-plate法)消煮浸提土样和植株粉末,再用电感耦合原子发射光谱仪(ICP-AES)检测分析样品中铬、镍、镉、砷和铅的含量。富集系数=植株内重金属含量/土壤内重金属含量×100%

## 1.3 数据处理与分析

利用WPS表格和SPSS 22进行数据整理和统计分析。

# 2 结果与分析

由图1可知,距离污染中心不同距离农田土壤




注:图中不同小写字母表示在0.05水平差异显著。下图同。

Note: The different lowercase letters in figure means significant difference at 0.05 level. The same below.

**图1 距污染中心不同距离农田土壤中的重金属含量**

Fig.1 Heavy metal content in farmland soil at different distances from the pollution center

中,重金属镍(Ni)和镉(Cd)表现出显著的随距离增加而减少的趋势,铬(Cr)、砷(As)和铅(Pb)没有表现出显著的变化趋势。在重金属含量方面,镍超标最严重(超过限值4.4 ~ 8.9倍),其次是镉(超过限值1.3 ~ 3.7倍),砷的含量接近限值(为限值的66.7% ~ 70.1%),铬和铅的含量则离限值较远(低于限值的60%)。

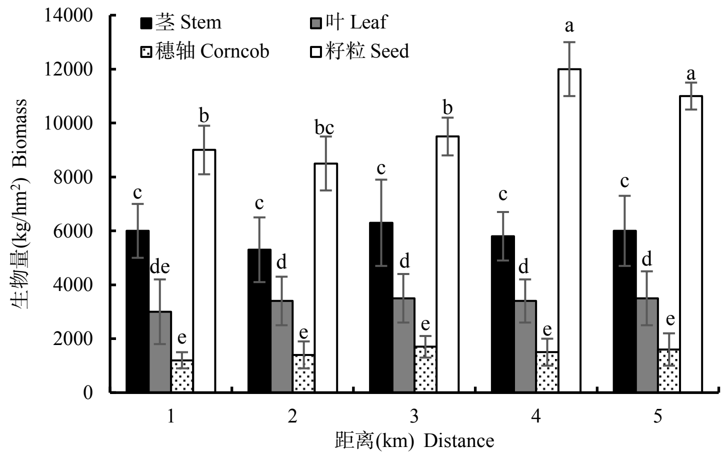
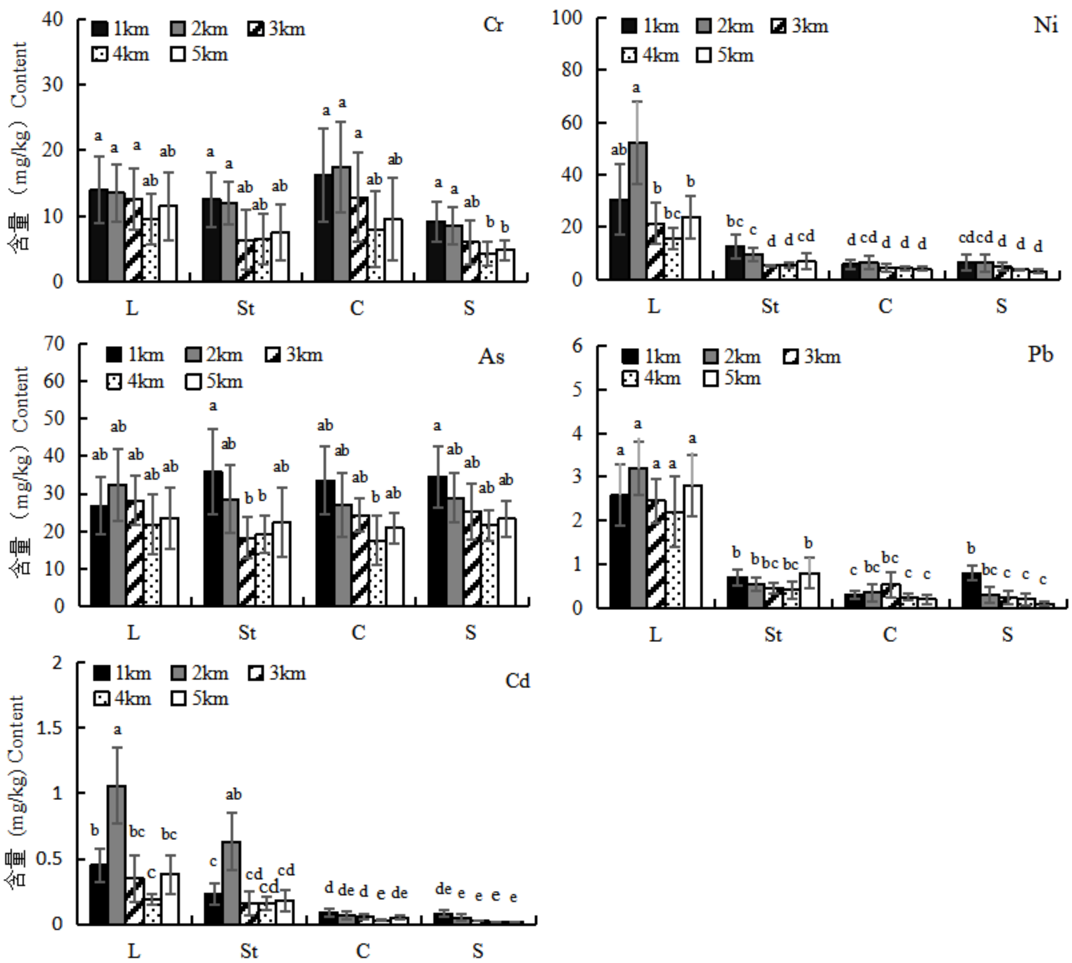


图2 距污染中心不同距离农田中玉米各器官的生物量

Fig.2 Biomass of maize organs in fields at different distances from the pollution center



注:图中L、St、C和S分别表示叶、茎、穗轴和子粒。

Note: L, St, C and S in the figure means leaf, stem, corncob, and seed, respectively.

图3 距污染中心不同距离农田中玉米的重金属含量

Fig.3 Heavy metal content of maize in fields at different distances from the pollution center

由图2可知,随着距离污染中心距离的增加,玉米的子粒生物量呈显著增加趋势,其中4~5 km处的玉米子粒生物量比1~3 km处的玉米子粒生物量高15.8%~31.7%;叶片生物量无显著差异,呈微弱增加趋势,增幅约为5.1%~10.8%;茎和穗轴的生物量无显著差异,未表现出增加或减少趋势。在距离污染中心较近的农田,玉米生长发育和子粒产量受到一定抑制。

由图3可知,随距离污染中心距离的增加,玉米各器官中各重金属的含量基本上呈显著减少趋势。从不同器官来看,砷在子粒中的含量最多(达21.4~34.5 mg/kg),其次是铬(达4.8~9.1 mg/kg),镍、镉和铅在子粒中的含量很少;在营养器官,特别是叶片中的含量远高于子粒。不同重金属在玉米体内的分布不同,在砷、铬超标的农田中应避免种植食用玉米。

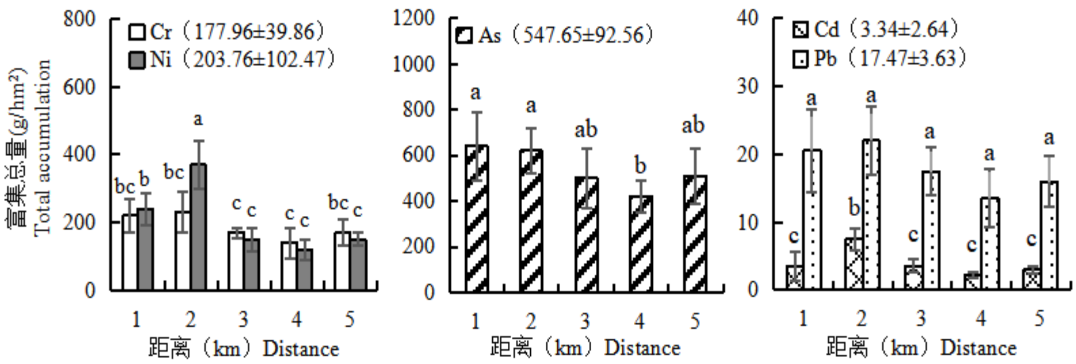



图4 距污染中心不同距离农田中玉米的重金属富集总量

Fig.4 Total accumulation of heavy metals in maize at different distances from the pollution center

由图4可知,随着距离污染中心距离的增加,农田中玉米对铬、镍、砷和镉的富集总量呈显著下降趋势,对铅的富集总量变化不显著。玉米对砷的富集总量最大(达547.65±92.56 g/hm²),对镍和铬的富集总量其次(分别为203.76±102.47和177.96±39.86 g/hm²),对镉和铅的富集总量最低(17.47±3.63和3.34±2.64 g/hm²)。利用玉米修复不同重金属的效果会有不同,修复镍、铬污染的效果最好,修复砷的效果其次,修复镉和铅的效果最差。

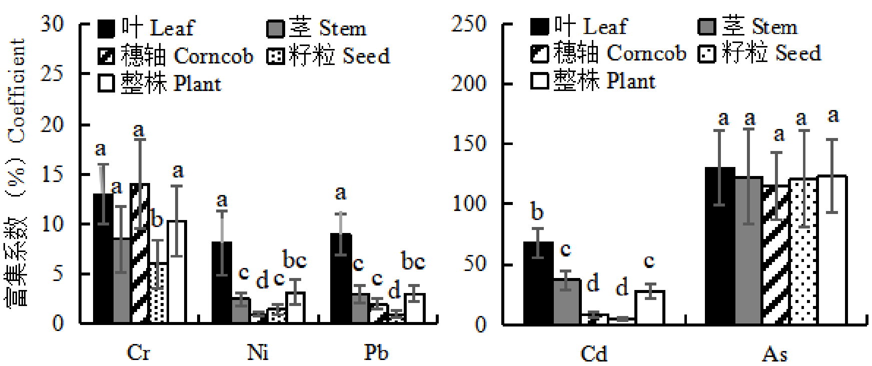



图5 污染中心周边农田中玉米对不同重金属的最大富集系数

Fig.5 Maximum enrichment coefficient of different heavy metals in maize in the fields surrounding the pollution center

由图5可知,玉米不同器官对重金属的富集系数中,整株和子粒对砷的富集系数都非常高(分别达123%和121%),其次是玉米整株和营养器官对镉的富集系数(28%~68%),对铬、镍和铅的富集系数整体上较低。玉米不同器官对重金属的富集偏好不同,玉米尤其倾向于将砷富集于子粒。

由表2可知,不同重金属的相关系数中,镍和镉为显著负相关,砷、铬和铅为不显著相关。不同重金属的漂移性不同,镍和镉漂移性较弱,砷、铬和铅的漂移性较强。在土壤重金属对玉米子粒和整株生物量的影响方面,镍、镉和砷的负相关性较强,铬和铅的相关性不显著。在玉米体内重金属的平均浓度和富集量方面,玉米对镍和砷的吸收均与土壤含量呈显著正相关,说明玉米更加偏好吸收土壤中的镍和砷。

**表2 不同要素组合的相关系数**

Table 2 Correlation coefficient of different factor combination

| 分析对象<br>Analysis object | 铬<br>Cr | 镍<br>Ni | 镉<br>Cd | 砷<br>As | 铅<br>Pb |
|---|---|---|---|---|---|
| 距离×土壤中的含量 | −0.315 | −0.847* | −0.909* | −0.441 | 0.281 |
| 土壤中的含量×子粒产量 | 0.154 | −0.565* | −0.739* | −0.735* | 0.259 |
| 土壤中的含量×生物量 | −0.017 | −0.727* | −0.794* | −0.716* | 0.055 |
| 土壤中的含量×植株体内浓度 | −0.029 | 0.551* | −0.106 | 0.676* | 0.319 |
| 土壤中的含量×整株富集量 | −0.125 | 0.699* | 0.271 | 0.893* | −0.066 |

注：表中正数表示正相关，负数表示负相关，*表示在0.05水平显著相关。

Note: In the table, positive number means positive correlation, negative number means negative correlation, with * means significant correlation in 0.05 level.

## 3 结论与讨论

矿区周边农田的重金属污染状况一直严重影响着当地粮食安全和生态安全。吉林省镍矿周边农田存在着不同程度的重金属污染。调查清楚土壤重金属的分布特征，才能制定有效的治理措施。在镍矿周边的农田土壤中，重金属镍(Ni)和镉(Cd)的含量会随着距离的增加明显降低，铬(Cr)、砷(As)和铅(Pb)的变化不明显。玉米群体的子粒和总生物量与土壤重金属含量均呈负相关，说明高浓度的重金属会抑制农作物生长，不同重金属的漂移性差别很大，镍和镉的漂移性弱，铬、砷、铅的漂移性强。

利用收益型植物修复土壤重金属，由于推广成本低，正成为一些地区治理土壤重金属污染的重要方案。玉米具有生物量大、种植面积大、可生产工业乙醇等突出优点，已经成为土壤重金属修复的热门植物。国外相关研究表明，利用玉米等生物能源型的植物对部分重金属污染土地进行修复和利用，具有广阔的发展前景。本研究结果显示，玉米对不同重金属的吸收和分配方面，表现出明显差异。玉米对土壤中镍、铬和砷的富集总量较多，对镉和铅的富集总量较少，并且倾向于将砷、铬富集于子粒，将镍、镉、铅富集于营养器官，说明利用玉米修复不同重金属的效果及由此引发的食品安全风险差别很大。在砷或铬超标的农田中，不适合种植食用玉米，对镍超标的土地而言，种植食用玉米的安全风险较低，也适合用玉米作修复植物。

本研究表明，土壤中不同重金属的漂移性差别很大，其中，镍(Ni)和镉(Cd)的漂移性较弱，砷(As)、铬(Cr)、铅(Pb)的漂移性较强。矿区周边土壤中，镍、镉、砷的浓度和玉米的子粒产量呈显著负相关，说明高浓度的重金属会抑制玉米的生长发育。玉米对不同重金属的吸收和分配有明显差别，尤其倾向于将砷和铬富集于子粒，将镍富集于营养器官，对铅、镉的富集量则很少。因此，玉米适合作镍的修复植物，在砷或铬含量高的土地不适合种植食用玉米。

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