Public Health

Heavy metal contamination in soil-rice system and its spatial variation in southeastern China: a review

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Food safety and the associated health risk is now one of the major concerns worldwide, especially in China. Rice is the dominant agricultural product in China and ranks second by quantity in the world. The quality of rice, thus, affects greatly human health. Among the factors influencing the food quality, soil contamination and the related quality are the main sources leading to the food contamination. It is very necessary to conduct some investigations on the contamination and relationship of heavy metals in the soil-rice system at a rice production region. The results will provide guidelines beneficial to soil quality improvement, scientific distribution of rice plant and food security in rice production areas. *Journal of Nature and Science, 1(3):e58, 2015.*

Heavy metal | Rice-production area environment | Soil-rice system | Bioavailability | GIS | Geostatistics

With the rapid development of industry and increasing release of agrochemicals into the environment worldwide, the potential accumulation of heavy metals in agricultural soil has caused a growing public concern on food security (Wong et al., 2002). Among the factors influencing the food quality, soil contamination and the related quality are the main sources leading to the food contamination. Among potential toxic pollutants, heavy metals can pose long-term environmental and health implication because of their non-biodegradability and persistence (Adriano, 2001; Huang and Gobran, 2005; Zhao et al., 2011). Recent rapid economic growth in China has led to an increasing serious problem of heavy metal contamination in agricultural soils (Chen et al., 1999; Huang et al., 2007). Therefore, heavy metals have attracted a great deal of attention worldwide and heavy metal contaminations in soils have been a focus of environmental studies. The study on the contamination of heavy metals in soil-rice system is important in order to protect soil quality and food security. Rice (*Oryza sativa* L.) is one of the most important agricultural crops in China. The quality of rice greatly affects human health, as consuming rice contaminated by cadmium (Cd), lead (Pb) and other metals can seriously deplete body stores of Fe, vitamin C and other essential nutrients, leading to decreased immunological defenses, impaired psycho-social faculties and disabilities associated with malnutrition (Liu et al. 2005). Therefore, it is of great importance to protect agricultural soil and ensure its sustainability.

Substantial research has been carried out to investigate the transfer of heavy metals in the soil-rice system and the mechanisms involved (Haldar and Mandal 1981; Wang et al. 2003; Cheng et al. 2004; Zeng et al. 2005). However, most of these previous studies were carried out on the basis of pot or filed experiments, and little information is available on present paddy fields at a large scale area. Therefore, it is very necessary to conduct some investigations on the contamination and relationship of heavy metals in the soil-rice system at a rice production region. The results will provide guidelines beneficial to soil quality improvement, scientific distribution of rice plant and food security in rice production areas.

The present research was conducted in three representative rice-production areas including Nanxun city, Shengzhou city and Wenling city, which are located in the north, middle and southeast Zhejiang province, respectively. 100, 94 and 96 pairs of rice grains and their corresponding soil samples were collected from the paddy fields in Nanxun, Shengzhou and Wenling, respectively, by means of a scientific sampling strategy design. The properties of rice and soil samples were further analyzed in the laboratory including metal total concentrations and fraction concentrations in soils, metal concentrations in rice grains, and soil physicochemical properties (pH, organic matter, electrical conductivity, soil texture). Based on GIS technique and some spatial analysis methods, we studied the spatial characteristics of heavy metals in soil-rice system at rice-production areas, which mainly included heavy metal contaminations, spatial variance, translocation, spatial relationship, influence mechanisms and quantitative models. The main results were summarized as follows:

(1) The background values of soils in Zhejiang province and the Environmental Quality for Soil in China were used as the basis for the threshold values for heavy metal pollution in the soil. The results indicated that Cd, Cu, Ni, Pb and Zn were enriched to different degrees in paddy soils of the study areas and some areas posted some contaminations of heavy metals. However, the quality of the paddy soils in the study areas was generally acceptable for agriculture production. All the mean values of heavy metal concentrations in rice were below the threshold values of Maximum Levels of Contaminants in Foods in China. Thus, the quality of the rice in the study areas was acceptable. Among the studied heavy metals, Cd was also the main pollutant in soil and rice, and posted potential risk in the rice-production areas.

(2) The concentrations of heavy metals in soil and rice of the study areas showed spatial variability and spatial patterns based on geostatistical analysis. A comparison of spatial distribution patterns of heavy metals in soil-rice system showed that rice Cd had the most similar spatial pattern to soil Cd; for other heavy metals, the spatial patterns in soil and rice showed similarity to some degree. The results illustrated that the heavy metals in rice are spatially correlated with that in soil to some degree and the transfer of heavy metals in soil-rice system may be affected by other factors besides the concentrations of heavy metals in soils.

(3) The correlations coefficients between heavy metals in the paddy soils and rice were calculated in the three rice-production areas. Among the studied metals, only Cd and Zn were significantly ($p<0.05$) correlated in soil-rice system with low correlations coefficients of 0.592 and 0.452, respectively. The result indicated that the total heavy metal concentrations alone in soil cannot reliably estimate the availability of most heavy metals to rice. Take Wenling as an example, cross-correlograms were further constructed to quantitatively determine the spatial correlation of heavy metal concentrations in rice and fraction concentrations in paddy soil. Cd and Zn in rice were strong spatial correlated with the exchangeable, organic bound and Fe-Mn oxide bound fractions; Ni in rice was strong spatial correlated with exchangeable fraction; Compared to other metals, Cu in rice was weak correlated with chemical fractions, and was strongest spatial correlated with organic bound fraction. Generally, the spatial correlation of heavy metals in soil-rice system was in the order of exchangeable fraction> organic bound fraction>Fe-Mn oxide bound fraction>residual fraction, reconfirming that the exchangeable fraction is considered as easily available fraction and has the highest bioavailability, while residual fraction is not considered to create a bioavailable pool and represents the least liable fraction.

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(4) Enrichment index (EI) was determined as a useful indication of the availability of heavy metals in soil-rice system. The absorption and accumulation of heavy metals in rice varied significantly ($p<0.05$) among metals, and was generally in the order of Cd>Zn>Cu>Ni. The highest availability of Cd in soil-rice system resulted in the high potential Cd risk in the rice-production areas. The concentrations of metal fractions exhibited significant difference and the distribution among the fractions differed between heavy metals, which may result in the different availability of heavy metals. Cd in the paddy fields occurred primarily in the non-residual fractions while the other heavy metals were predominantly associated with the residual fraction and lowest bound in exchangeable fraction. The potential bioavailability of heavy metals in the paddy fields was generally in the order of Cd>Pb>Zn>Ni=Cu. Because of the higher bioavailability, the transfer of Cd in soil-rice system was higher than that of other heavy metal.

(5) Take Wenling as an example, rice genotype and soil properties were considered as the factors to study their influence on the transfer and bioavailability of heavy metals in soil-rice system in rice-production areas. The spatial distribution of rice genotypes in the study area played some role on the spatial variance of enrichment index of heavy metals. Soil types also played some role on influencing the transfer of heavy metals in soil-rice system in rice-production areas. Cross-correlograms further quantified the spatial correlation between the availability of heavy metals (EIs) and soil properties. The EIs of Cd，Ni and Zn were strongest spatial correlated with soil pH, OM, EC, however, they were poor correlated with Fe oxide; the EI of Cu was relatively weaker correlated with soil properties, moreover, there was no correlations between EI of Cu and soil pH and OM. The results indicated that soil properties did influence the transfer of heavy metals in soil-rice system in rice-production areas. Among these properties, soil pH and OM generally had the most significant effect. Soil properties studied had relatively weak effect on the Cu availability. The correlation coefficients further showed that metal fractions were significantly correlated with relative soil properties, revealing soil properties especially soil pH and OM do exhibit noticeable influence on the distribution of heavy metals in fractions and then influence the bioavailability of heavy metals to rice plant.

(6) The transfer and bioavailability of heavy metals in soil-rice system in the three rice-production areas were studied. The transfer (EI) of heavy metals in the soil and rice system was in the order of Shengzhou>Wenling>Nanxun. The results of ANOVA analysis further indicated that the largest and significant factor on the transfer and bioavailability of heavy metals in soil-rice system of the rice production areas was genotype by environment interaction, followed by environment effect, then genotype effect. Among the environment factors including metal fractions and soil properties, the effect of soil properties was higher. Thus, the significant differences of the transfer of heavy metals in soil-rice system in the three rice production areas were mainly duo to the interaction of genotype by soil properties.

(7) The development of transfer models of heavy metals for Hybrid rice and Japonica rice focused on Shengzhou and Nanxun, respectively. The logarithmic linear models simulated for the two rice genotypes based on multivariance regression analysis, can both significantly describe the quantitative relationship between the transfer (EI) of heavy metals in soil-rice system and the environment factors including metal fractions and soil properties. The developed transfer models further significantly predicted the transfer and bioavailability (EI) of most heavy metals in soil-rice system in Wenling study area. However, it failed to predict the transfer of Cd in soil-rice system for Hybrid rice since correlation coefficient between predicted and measured EIs. Furthermore, the models would highly predict the EIs while the measured EIs were low for some heavy metals. The results suggested the models in the study can well predict the transfer of heavy metals in soil-rice system of rice production areas, and further improvement may be also welcomed.

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