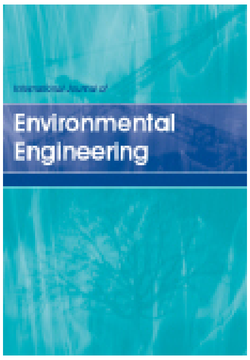

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Abstract: The emergence of vegetable greenhouses greatly improves the yield and diversity of vegetable crops, but has a negative impact on the soil. This paper briefly introduced the vegetable greenhouse and the methods used for evaluating the soil ecological risk and took a vegetable planting base in Yichang City of Hubei Province as the subject to carry out the soil pollution management and ecological risk analysis in the greenhouse planting area. The results showed that the content of heavy metals in the soil and the ecological risk increased with the continuous use of the greenhouse; after using organic fertiliser instead of chemical fertiliser, the content of heavy metals in the soil of both open-air farmland and greenhouse farmland were reduced, especially in the greenhouse farmland, in which the ecological risk was also reduced. Then, according to the test items and results, several suggestions were put forward for the soil pollution management of greenhouse vegetable planting.

Keywords: greenhouse; vegetable; soil pollution; ecological risk.

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1 Introduction

As a kind of healthy food, vegetables are in increasing demand (Papaioannou et al., 2017). In traditional agriculture, the open-air cultivation of crops depends on changes in weather, climate, etc.; once the environment changes, the yield or quality will reduce, which is not stable (Papaioannou et al., 2019). When using the greenhouse for vegetable planting, the closed nature of the greenhouse can maintain the stability of the planting environment as far as possible, and it can also manually regulate the vegetable planting environment and get rid of the dilemma of relying on nature, which is conducive to the improvement of yield and quality (Zhang et al., 2017). However, although greenhouse planting can improve crop yield and quality, it also has its drawbacks. Even if on the conventional open-air land, after continuous planting and fertilisation, the soil in the planting area will be inevitably affected by acidification, hardening, heavy metal pollution, etc., and the above influence will be more serious due to the closure of the greenhouse, especially the heavy metal pollution. Once the enrichment of heavy metals enters the food chain, it will produce adverse effects on food security and human body health. Therefore, the analysis and management of soil pollution and ecological risk assessment of greenhouse vegetable planting areas is a very crucial part of the planting industry. Sungur et al. (2016) evaluated the environmental impact of heavy metals in greenhouse and field samples using the pollution factor method, potential ecological risk index method and risk assessment method. The results showed that the soil pH value and organic matter content were highly correlated with the content of heavy metals in greenhouse soil. Fan et al. (2017) evaluated the accumulation characteristics and potential risks of heavy metals in the soil-vegetable system under greenhouse conditions. The results showed that Cd showed a relatively larger transfer factor in three kinds of vegetables, with a relatively low total concentration and a high proportion of available form in soils. Chen et al. (2016) investigated the soil in the solar greenhouse around the Bohai Gulf area under different planting years and environmental conditions to study the effects of planting years and biogeographical conditions on soil nutrients, heavy metals, and phthalate esters and found that soil pH value decreased, and soil conductivity, organic matter, and total nitrogen content increased with the extension of cultivation time. The researches mentioned above are about the detection of the degree of soil pollution and influencing factors and have obtained relevant conclusions. The main purpose of this article is also to explore the impact of vegetable greenhouses on the soil through the detection of soil pollution in the greenhouse planting area. Then, based on the results of the research, specific suggestions were made on the soil protection in the vegetable greenhouse. This paper briefly introduced the vegetable greenhouse and the methods used for evaluating the soil ecological risk and took a vegetable planting base in Yichang City of Hubei Province as the subject to carry out the soil pollution management and ecological risk analysis. This paper analysed the effect of vegetable greenhouses on the pollution degree of heavy metals in soils through detecting the pollution of heavy metals in the soil in greenhouse and comparing it with that in the non-greenhouse soil in an adjacent area. This work provides an effective reference for protecting the soil safety and sustainable development in the planting area.

2 Vegetable greenhouse, soil pollution and ecological risk

2.1 Brief introduction of vegetable greenhouse

Traditional agricultural planting is usually carried out in the open-air; as a result, the planting time and yield of different crops are usually subject to the change of seasons. The appearance of a vegetable greenhouse overcomes the defect that the weather restricts vegetable planting to a certain extent. A vegetable greenhouse is a kind of frame and film-covering structure with a heat preservation function. The structure is made of bamboo or steel and covered with single or multiple layers of heat preservation film, thus forming a relatively closed space. In this space, the concentration of carbon dioxide produced by vegetable respiration will gradually rise, which is conducive to the photosynthesis of vegetables and enhances heat preservation to keep the environment temperature suitable for vegetable growth in the greenhouse (Cayir et al., 2017). Thanks to the film covering with heat preservation function, the relatively stable vegetable growth environment can be maintained in the relatively closed greenhouse space. With the help of manual adjustment, a greenhouse environment with a large difference with the outside environment can even be achieved to realise the possibility of off-season vegetable planting and further improve the variety and yield of vegetable production (An et al., 2020). The greenhouse used for vegetable planting has different specifications and types according to the planting demand (Tian et al., 2017).

2.2 Soil pollution in greenhouse and calculation of ecological risk

From the above introduction of vegetable greenhouses, we can see that one of the advantages of greenhouses is that they can artificially adjust the growth environment of vegetables and maintain stability, which cannot only improve the seasonal diversity of vegetable production but also increase the yield of vegetables (Zou et al., 2015). The greenhouse can realise the artificial adjustment of vegetable planting environment by depending on the sealing of the planting environment formed by the frame and film covering, but it also brings adverse effects. One is that the plastic film (Aslam et al., 2019) will remain in the soil after it is removed after its service life, and the hard-to-degrade film with poor permeability will reduce soil porosity, making the water at the bottom difficult to rise to the surface layer through capillary action and aggravating soil hardening (Wang et al., 2018). The second is that both sides of the plastic film will be deeply buried in the soil to be a barrier in the process of greenhouse construction; however, chemical fertilisers and pesticides in the greenhouse cannot be normally discharged, salts in the soil cannot spread normally, and the content of harmful substances such as pesticides, heavy metals, and salts in the greenhouse will exceed the normal limit after long-term accumulation.

Although the use of greenhouses can improve the yield of vegetables, it will also aggravate the degree of heavy metal pollution in the soil due to its sealing. In order to improve the yield of vegetables and ensure the reduction of heavy metal pollution in the land, it is necessary to manage the soil pollution in the greenhouse planting area. In the process of management, a comprehensive standard is needed to judge the degree of heavy metal pollution to assist soil pollution management. The calculation formula of the ecological risk analysis (Lv et al., 2015) is:

$$\begin{cases} P_i = \dfrac{C_i}{S_i} \\ E_i = T_i \cdot P_i \\ RI = \sum E_i \end{cases} \quad (1)$$

where P_i stands for the single pollution index of heavy metal *i*, C_i stands for the measured mass fraction of heavy metal *i* in soil, S_i stands for the background mass fraction of heavy metal *i* in the soil (the content of heavy metal *i* in normal soil), E_i stands for the single potential ecological risk index of heavy metal *i*, T_i stands for the toxicity response coefficient of heavy metal *i*, and *RI* stands for the comprehensive potential ecological risk index of all heavy metals. The larger the value of *RI* is, the greater the toxicity level of heavy metals in soil and their harms to the soil will be.

3 Case analysis

3.1 Overview of the study area

In this study, the analysis of soil pollution management and ecological risk in the greenhouse planting area was carried out by taking a vegetable planting base in Yichang City of Hubei Province as the subject. Located in the transition zone between the middle subtropical region and the north subtropical region, this area has the subtropical monsoon humid climate (Bai et al., 2015), with four distinct seasons and raining and hot in the same period. The average annual rainfall is 1,215 mm, and the average temperature is 16.9℃. The vegetable planting base has 540 mu of directly owned farmland and 12,000 mu of franchised farmland. There are 600 greenhouses in the directly owned farmland.

3.2 Sample collection

This study mainly analysed the effects of management methods of ‘controlling the service life of greenhouse’ and ‘reducing the use of chemical fertiliser and using organic fertiliser instead’ on soil heavy metal pollution and ecological risk in greenhouse planting area; therefore, it is necessary to set the corresponding area when collecting soil samples. Firstly, the samples used for studying the impact of greenhouse service life on soil were collected from the open-air farmland where the greenhouses have never been used and the farmlands where have used greenhouses for 1, 2, 3, 4 and 5 years. The latter only had a difference in the service life of the greenhouse and had no difference in the other items, such as types of vegetables planted and chemical fertiliser applied. Secondly, the samples used for studying the impact of ‘using organic fertiliser instead of chemical fertiliser’ on soil were collected from the open-air farmland that has never used greenhouse but used chemical fertiliser, the open-air farmland that has never used greenhouse but used organic fertiliser, the farmland that has used greenhouse and chemical fertiliser for two years, and the farmland that has used greenhouse and organic fertiliser for two years.

The same sampling method was used in different sampling areas mentioned above: five sampling points were evenly selected along the diagonal line in the greenhouse, soil was collected at a depth of 0~20 cm from the sampling points and the surrounding four sub-sampling points and evenly mixed and sieved by 2 mm sieve meshes, and the screened soil samples were properly preserved for future experiments.

3.3 Experimental methods

3.3.1 Determination of heavy metals in soil samples

1 0.3 g of the soil sample was weighed by an electronic balance and put into a 50 ml digestion tube.

2 9 ml of HNO_3, 3 ml of HF, and 1.5 ml of H_2O_2 were added to the digestion tube in turn.

3 After mixing, the digestion tube was put into a microwave digestion instrument (Elkhatib et al., 2018) for digestion.

4 The digested sample was detected using an inductively coupled plasma optical emission spectrometer (ICP-OES) to obtain the content of heavy metals such as As, Cd, Cr, Pb, and Cu in the soil sample.

3.3.2 Potential ecological risk test of the soil sample

When using the ecological risk index method, besides collecting the content of pollutants to be evaluated in the collected soil samples, the soil background value was needed as the reference standard. In this study, the soil background value of Hubei Province in Background Value of Soil Elements in China (State Department of Environmental Conservation, China National Environmental Monitoring Centre, 1990) was used as the reference standard. The background values of heavy metals in soils required by this paper are shown in Table 1. The toxicity response coefficient of As, Cd, Cr, Pb, and Cu was 10, 30, 2, 5 and 5, respectively. Table 2 shows the soil ecological risk classification.

Table 1 Pollution background value

Heavy metal	*As*	*Cd*	*Cr*	*Pb*	*Cu*
Soil background value mg/kg	12.3	0.172	86.0	26.7	30.7

Table 2 Soil ecological risk classification

Ecological risk degree	*Comprehensive pollution index of heavy metals (RI)*
Mild risk	RI < 150
Moderate risk	150 ≤ RI < 300
Strong risk	300 ≤ RI < 600
Very strong risk	RI ≥ 600

3.4 Test results

In this study, the heavy metal content in soils under greenhouses with different service time was tested, and the results are shown in Table 3. According to the test results of the heavy metal content in the soil, the corresponding soil ecological risk was calculated, and the calculation results are shown in Figure 1. First of all, by observing the heavy metal content in soils under greenhouses with different service time in Table 3, it was found that the distribution proportion of different heavy metals in the soil of the open-air farmland and the farmland under greenhouses with different service time was quite similar, and the content of Cr was the highest, followed by Cu, Pb, As and Cd. The comparison of the content of the same heavy metals between different farmlands found that the content of heavy metals in the open-air farmland was the least, and the content of heavy metals in the soil of the planting area increased with the increase of the service time of greenhouse. It was directly seen from the soil ecological risk in Figure 1 that the ecological risk of the open-air farmland was in a mild risk, but its comprehensive ecological risk index gradually rose with the increase of the service time of greenhouse. Although the ecological risk of the soil in the greenhouse used for only one year has increased, it was still in a mild risk; the soil in the greenhouse used for 2 or 3 years has gradually in a medium risk, which needed pollution control; the greenhouse under the greenhouse used for 4 or 5 years has been in a strong risk, which needed corresponding measures to reduce the heavy metal pollution to prevent the vegetables produced in the greenhouse from causing serious harms to human health.

Table 3 Content of heavy metals in soils in greenhouses with different service time

	Open-air farmland	*Farmland under the greenhouse used for one year*	*Farmland under the greenhouse used for two years*	*Farmland under the greenhouse used for three years*	*Farmland under the greenhouse used for four years*	*Farmland under the greenhouse used for five years*
As mg/kg	13.3	25.3	45.4	65.3	75.1	89.8
Cd mg/kg	0.186	0.203	0.326	0.445	0.552	0.621
Cr mg/kg	86.8	436	1102	1858	2464	2761
Pb mg/kg	26.9	60.6	141	236	294	338
Cu mg/kg	31.7	75.7	181	304	345	394

Figure 1 Ecological risks of soils in greenhouses with different service time

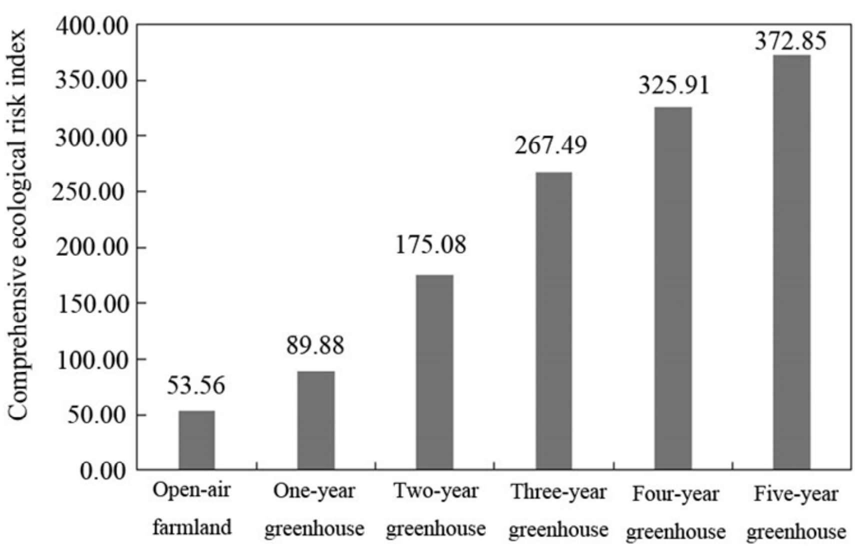

Figure 2 Ecological risks of the open-air farmland and the farmland in the greenhouse used for two years under application of different fertilisers

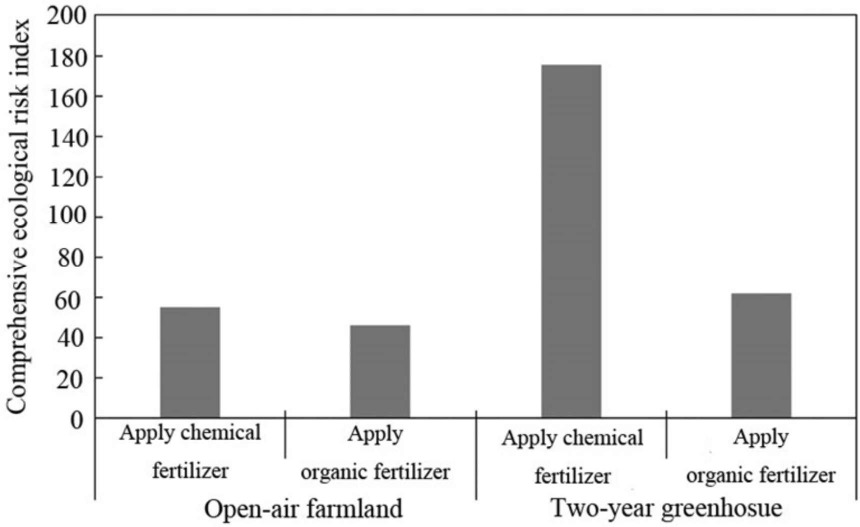

Table 4 Content of heavy metals in the open-air farmland and the farmland in the greenhouse used for two years under application of different fertilisers

	Open-air farmland		*Farmland in the greenhouse used for two years*	
	Apply chemical fertiliser	*Apply organic fertiliser*	*Apply chemical fertiliser*	*Apply organic fertiliser*
As mg/kg	13.3	10.2	45.4	19.4
Cd mg/kg	0.186	0.163	0.326	0.183
Cr mg/kg	86.8	74.3	1102	102
Pb mg/kg	26.9	20.11	141	30.6
Cu mg/kg	31.7	24.3	181	39.6

This study also tested the heavy metal content in the open-air farmlands applied with different fertilisers and the farmland applied with different fertilisers under the greenhouse used for two years. The reason for choosing the two-year greenhouse was that two years was enough for producing differences between the open-air farmland and the farmland under the greenhouse and also enough for avoiding the situation that it was difficult to confirm that the increase in heavy metals was mainly caused by fertilisers. The results are shown in Table 4. Then, the ecological risk was calculated according to the heavy metal content, and the results are shown in Figure 2. It was found from Table 4 that the distribution proportion of heavy metals were similar in soils whether the greenhouse was used or not and whether chemical fertiliser was replaced by organic fertiliser, and the content of Cr was the highest, followed by Cu, Pb, As and Cd. The comparison between the farmland applied with chemical fertiliser and the farmland applied with organic fertiliser demonstrated that the content of heavy metals in the farmland applied with organic fertiliser decreased, especially in the farmland in the greenhouse. By observing the soil ecological risk shown in Figure 2, it was found that the comprehensive ecological risk index of the farmland applied with organic fertiliser was lower, whether it was the open-air farmland or the farmland in the greenhouse; especially in the greenhouse farmland, the ecological risk of the farmland with organic fertiliser was far lower than that of the farmland applied with chemical fertilisers.

4 Discussion and suggestions

In this paper, the heavy metal pollution degree and ecological risk of the soil in the vegetable planting area were tested and analysed in aspects of the service time of greenhouse and the use of organic fertiliser instead of chemical fertiliser, and several management suggestions were given from the above two aspects according to the results. According to the above results, the heavy metal content in the soil of the vegetable planting farmland increased after the use of the greenhouse, which led to the increase of ecological risk. With the increase of the service life of greenhouse, the heavy metal content in the soil and ecological risk also increased. When the greenhouse was used for more than four years, the ecological risk was strong, which was difficult to ensure vegetable planting safety. When using organic fertiliser instead of chemical fertiliser, the content of heavy metals and ecological risk in the farmland decreased, especially in the farmland in the greenhouse. The reasons for the above results were analysed. Firstly, plastic films were deeply buried on both sides of the greenhouse to ensure the sealing; however, the heavy metals caused by irrigation and fertilisation in the greenhouse could not be discharged with the water and intercepted in the greenhouse. With the increase of the greenhouse service time, the intercepted heavy metals gradually accumulated, leading to the deepening of heavy metal pollution and the increase of ecological risk. Different heavy metal impurities were produced due to various chemical reactions in the production process of chemical fertiliser, and long-term use of chemical fertiliser in farmland might lead to the accumulation of heavy metals. Organic fertiliser produces nutrients for vegetable growth by taking advantage of microbial community decomposition; thus, as long as the organic matter itself did not have heavy metal pollution, the decomposition process would not introduce heavy metals, thus reducing the risk of heavy metal pollution in farmland. The difference in the greenhouses when different fertilisers were used was because the accumulation of heavy metals in the open-air farmland with good permeability was slow, but the sealed greenhouse had more accumulation of heavy metals when chemical fertiliser was used.

It is necessary to manage the heavy metal pollution in greenhouses to reduce the ecological risk of farmlands in vegetable greenhouses and improve the safety of vegetables. Based on the above results and analysis, the author puts forward the following suggestions:

1. The long-term continuous use of vegetable greenhouses should be avoided as far as possible. When the greenhouses have been used for two years, they should be removed in time, and there should be no plastic film residue in the farmland.
2. The use of chemical fertiliser should be gradually reduced and replaced by organic fertiliser. Finally, the fertilisation scheme for vegetables should be adjusted as ‘organic fertiliser first, chemical fertiliser second’.

3 The soil in the greenhouse should be sampled regularly, and the content of heavy metals should be detected to evaluate the potential ecological risk of the soil. The greenhouse with high ecological risk should be treated in time. When the ecological risk of the open-air farmland is reduced to the normal level, building new greenhouses can be considered.

5 Conclusions

This paper briefly introduced the vegetable greenhouse and the methods used for evaluating the soil ecological risk and took a vegetable planting base in Yichang City of Hubei Province as the subject to carry out the soil pollution management and ecological risk analysis in the greenhouse planting area. The results are as follows:

1 The distribution proportion of different heavy metals in the farmland of the base was quite similar, and the content of Cr was the highest, followed by Cr, Cu, Pb, As and Cd.

2 With the increase of the service time of greenhouse, the content of heavy metals and the potential ecological risk of the soil in the planting area increased.

3 After using organic fertiliser instead of chemical fertiliser, the content of heavy metals and the potential ecological risk in the soil of the planting area decreased, especially the soil in the greenhouse.

4 According to the results of case analysis, three suggestions for the management of soil pollution in vegetable greenhouses were put forward.

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