Technique of Earthworms Restoring Soil in Greenhouse Cultivation

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Abstract The production environment of greenhouse cultivation is relatively closed, the multiple cropping index is high, the management of fertilization, watering and pesticide application is blind to some extent, and the phenomenon of continuous cropping is also common. Soil quality affects the sustainable development of greenhouse cultivation. Earthworm is a ubiquitous invertebrate organism in soil, an important part of soil system, a link between terrestrial organisms and soil organisms, an important link in the small cycle of soil material organisms, and plays an important role in maintaining the structure and function of soil ecosystem. Different ecotypes of earthworms are closely related to their habitats (soil layers) and food resource preferences, and then affect their ecological functions. The principle of earthworm regulating soil function is essentially the close connection and interaction between earthworm and soil microorganism. Using different ecotypes of earthworms and biological agents to carry out combined remediation of greenhouse cultivation soil is a technical model to realize sustainable development of greenhouse cultivation.

Key words Earthworms, Greenhouse cultivation, Soil remediation, Biological agent

1 Introduction

Greenhouse cultivation uses greenhouse for protective cultivation of plants, and can change the limiting factors of traditional agroforestry and enable agroforestry resources to be effectively allocated and utilized according to people's wishes. It is a new and efficient modern mode of production and management of agriculture and forestry. In greenhouse cultivation, solanaceous fruits, melons, vegetables and other crops with high economic added value are mainly planted, with high multiple cropping index, great flexibility, high production efficiency and good economic benefits. It is an important part of modern agroforestry. Protected agriculture in China has developed rapidly. In the 1970s, the area of protected agriculture was only 6 700 ha; according to rough statistics, the area of protected agriculture was about 3 million ha in China in 2018, and the total output of protected vegetables exceeded 170 million t, accounting for 25% of the total output of vegetables in China, ranking first in the world. However, with the continuous degradation of soil quality, the sustainability of facility industry, food safety and environmental problems in greenhouse cultivation have become increasingly prominent, and the activities and metabolites of earthworms have a good effect on soil improvement[1]. The research on the technique of earthworm restoring soil in greenhouse cultivation will provide a theoretical basis for the healthy and sustainable development of protected agriculture, and provide technical support for increasing farmers' income and improving agricultural economic development.

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2 Soil in greenhouse cultivation

2.1 Soil quality deterioration caused by greenhouse cultivation Greenhouse cultivation is an irreplaceable production mode to effectively improve unit output value under the condition of land shortage, but the deterioration of soil quality caused by greenhouse cultivation restricts the sustainable development of this production mode. The greenhouse cultivation adopts glass greenhouse, solar greenhouse, plastic greenhouse, film mulching cultivation, *etc.* The environment is highly intensive and relatively closed, with no natural rain erosion and leaching, no slack winter season. The multiple cropping index is high and the continuous cropping is common. High input induced by high output is often blind. Fertilization, pesticide application and watering are frequent and large in amount. The input of fertilizer and water in some greenhouse cultivation systems is several times or even ten times that of ordinary fields, far exceeding the demand of crops in the current season in greenhouse cultivation systems. In addition to being absorbed by crops, most of the fertilizers applied in open field cultivation are washed away by rainwater, and only a small part of the fertilizers remain in the soil. However, the soil in greenhouse cultivation is not directly washed away by rainwater, and all the remaining fertilizers remain in the soil. The utilization rate of phosphate fertilizer is only 11% or even lower, and the nutrients of nitrogen, phosphorus and potassium in the soil are surplus, resulting in "soil eutrophication". Liu Wei *et al.*[2] studied the soil pH, soil organic matter and nitrogen accumulation and vertical profile characteristics of protected vegetable land, open vegetable field and cotton planting land in the suburbs of Wuhan. Due to the high input of acidic fertilizer in protected vegetable fields, the pH of protected vegetable fields is relatively low, the content of organic matter in topsoil is higher than that in open vegetable fields and cotton planting fields, and the difference in the content of total nitrogen and alkali-hydrolyzable nitrogen is similar to the difference in the content of organic matter. Nitrate nitrogen is accumulated obviously in the topsoil of greenhouse cultivation land, many times higher than that in the topsoil of open vegetable field and cotton planting land, resulting in a great waste of resources, and at the same time affecting the plant absorption of other nutrients and the environmental behavior in soil[2].

At present, the water utilization rate of greenhouse cultivation in China is not high. Taking protected vegetables as an example, the water utilization rate per unit area of protected vegetables in China is only 1/6 – 1/5 of that in Israel. In addition, in greenhouse cultivation, the blind application of acidic chemical fertilizer such as sulfuric acid compound fertilizer leads to soil acidification or the temperature in the greenhouse cultivation facilities is high and the evaporation is huge, and the salt is accumulated in surface soil to form secondary salinization. Fertilization and trampling in the process of cultivation and management lead to the destruction of soil aggregate structure, less soil aggregates, soil hardening, poor soil aeration, less beneficial soil microorganisms, low soil enzyme activity, accumulation of soil-borne pathogens and pests, decline of crop quality, more pesticide residues and other soil problems[2-4].

2.2 Decreasing soil quality in greenhouse cultivation with the increase of planting years Relevant studies show that the soil environmental quality in cultivation facilities gradually decreases with the increase of planting years. For the problem of soil environmental quality decline caused by greenhouse cultivation, Huang Dezhi *et al.* [4] studied the soil with depth of 0 – 20 cm and 20 – 40 cm in 12 solar greenhouses in Shuichuan Town, Baiyin City, Gansu Province in 1, 5, 10 and 15 planting years. The soil pH of solar greenhouse gradually decreased with the extension of planting years. Compared with the adjacent open vegetable fields, the soil total salt and nitrate content in solar greenhouse with different planting years was significantly higher than that in open vegetable fields due to intensive planting, high application rate of nitrogen fertilizer, phosphate fertilizer and potassium fertilizer, and weak rainfall leaching effect, and gradually increased with the increase of planting years, and accumulated in the topsoil for a long time. In greenhouse cultivation, the increase of organic matter, alkali-hydrolyzable nitrogen, available phosphorus, available potassium, pH and electrical conductivity in 1-year greenhouse was usually weak compared with the corresponding open field; the increase of organic matter, alkali-hydrolyzable nitrogen, available phosphorus, available potassium, pH and electrical conductivity in 3-year greenhouse increased obviously compared with the corresponding open field; after planting in greenhouse for about 10 years, the growth rate of organic matter, alkali-hydrolyzable nitrogen, available phosphorus and available potassium would generally decline, but the growth rate of conductivity and pH could reach the highest[4]. Dong Yan *et al.* [5] sampled typical greenhouse soils in the main vegetable and flower producing counties in Kunming suburbs, and studied the effects of different planting years on the nutrient status and soil microflora of protected soil. It was also found that after the production mode was changed from field cultivation to greenhouse vegetable protection, the soil ecological environment was good at the initial stage of greenhouse cultivation; after 6 – 8 years of planting, soil salt accumulation, nutrient enrichment and soil acidification were serious, soil microflora was out of balance, microbial diversity and uniformity decreased significantly, and soil quality stability and sustainable utilization were greatly reduced.

The results showed that the soil barrier factors in greenhouse (planting for more than 3 years) usually appeared obviously, so it is necessary to take intercropping and crop rotation or paddy-upland rotation in time to slow down the formation of barrier factors; for greenhouses (planting for more than 8 years), the soil barrier factors were rapidly formed and the soil salinization was obvious. The most effective way is to change the facility site to solve the influence of soil barrier factors on plant growth.

3 Technique of earthworms restoring soil

3.1 Effect of earthworm activity on soil quality Earthworms are invertebrates with the largest biomass in soil and an important part of soil system, accounting for 60% – 80% of the total animals in soil. It can improve soil through its own life activities, such as movement, feeding, digging and so on, so it is an important part of material circulation. As an "ecosystem engineer", it plays an important role in maintaining the structure and function of soil ecosystem. Strengthening the ecological service function of earthworms and improving the self-regulation ability of soil processes are beneficial to promoting the sustainable development of ecological greenhouse cultivation. Taking the practice of returning crop stalks to the field as an example, straw returning has been widely used in agricultural production in China. Earthworms accelerate the decomposition process of straw through a series of life activities such as crushing, feeding, digesting and digging holes, and promote the transformation of fresh straw residues into soil humus. Especially, the high enzyme activity (such as cellulase) in earthworm intestine can transform some refractory substances into easy-to-use organic matter, which can be removed from the body with wormcast. It is convenient for microorganisms to make better use of it and enhance the circulation and decomposition rate of soil nutrients[6]. Earthworm activity can also mix mineral soil with organic matter to form soil micromasses rich in organic matter, which significantly improves the physical structure of soil. With the increase of earthworm culture years, the soil bulk density decreases, the porosity increases, and the soil's ability to conserve water becomes stronger. Earthworm activity can also affect soil regulatory factors such as pH in the process of affecting ecosystem material cycle and energy flow. Many studies have shown that wormcast has a large acid-base buffer capacity. Zhao Jie *et al.* [1] found in the study of the Yellow River sandy plain that the long-term earthworm culture for 5 years would significantly reduce the bulk density and pH of alkaline soil and significantly increase the organic matter content; the changes of these indexes were not significant in the short-term earthworm culture for one year, but the difference of soil water content was significant compared with the control in both long-term and short-term earthworm culture.

In addition, different ecotypes of earthworms are closely related to their habitats (soil layers) and food resource preferences, and then affect their ecological functions. Surface earthworms have low bioturbation ability and feed on organic matter, which can significantly promote nitrogen mineralization; inner earthworms mainly live in soil, have high bioturbation ability, and prefer to feed on soil rich in organic matter, which can mix organic matter with soil well[7].

3.2 Improvement of soil structure and function by earthworm cast Earthworms excrete nutrient-rich wormcast when they move in soil. Wormcast has porous structure, and more humus in wormcast can combine with clay particles to form aggregates, which can improve soil structure and function. With the gradual development of earthworm breeding industry, wormcast is widely used in soil water conservation and fertilization, remediation of heavy metal pollution, inhibition of crop diseases and improvement of crop quality. Li Yanpei *et al.* [8] studied the influence of wormcast application method and amount on soil water infiltration process through indoor soil column simulation test. The soil used in the test was Lou soil, which had heavy soil texture, few macropores and water conduction pores, and high degree of soil pore bending, so it was often difficult for water to infiltrate into the soil. The application of wormcast into the upper soil effectively promoted the downward infiltration of water. And because of the good aggregate structure of wormcast itself, its water retention capacity is strong. When the application amount of wormcast is large, most of the water will accumulate in the wormcast layer, thus inhibiting the infiltration of soil water to the lower layer and increasing the effectiveness of soil water. Zhou Dongxing *et al.* [9] studied the effects of wormcast combined with chemical fertilizer on soil properties and enzyme activity in paddy fields, and proved that wormcast combined with chemical fertilizer had great application potential in improving soil nutrients and enhancing soil activity. In addition, organic fertilizer combined with chemical fertilizer has the advantages of fast-acting property and durability, and applying wormcast can be used as an important measure to improve soil. Cai Yonggang *et al.* [10] used pot experiments to study the effects of wormcast and cow dung on the growth of Chinese cabbage and the accumulation of cadmium and copper in the soil polluted by cadmium (Cd) and copper (Cu). Under the pollution of high concentration of Cd and Cu, the yield increase effect of wormcast was better than that of cow dung, and the accumulation of Cd in Chinese cabbage increased with the increase of soil Cd and Cu concentration. The results of crop planting also showed that wormcast was better than cow dung in restoring the soil polluted by Cd and Cu.

In addition, the role of wormcast in controlling soil-borne diseases has gradually become the focus of applied research at present. Adding proper amount of wormcast to cultivation substrate has certain control effect on some common soil-borne diseases such as *Rhizoctonia*, *Fusarium* wilt and damping-off disease. Wormcast can inhibit the damping-off disease caused by *Rhizoctonia solani* and *Fusarium* wilt caused by *Fusarium* at cucumber seedling stage. When the volume ratio of wormcast to soil is 20%, the control ability is better, and even the control effect can reach more than 90%. Liu Dawei *et al.* [11] studied the control effect of wormcast and extract on tomato root-knot nematodes through indoor bioassay and pot experiment, and found that wormcast extract showed obvious inhibition on oocysts and egg hatching of south root-knot nematodes. When the concentration of extract was 90%, the relative inhibition rate of oocyst hatching could reach 71.63%, which had obvious lethal effect on the second instar larvae, with a mortality rate of 88.46%. Potted substrates mixed with wormcast could also play a certain role in controlling tomato root-knot nematodes. When the proportion of wormcast to cultivation substrates was 75%, the control effect on root-knot nematodes could reach more than 70%. The application of wormcast could bring a large quantity of organic materials, trace elements, growth hormones and various enzymes into soil, thus effectively increasing crop yield and improving crop quality. Compared with cow dung compost fertilizer, the fructose content, vitamin C content and soluble protein content of pear fruit with wormcast combined with slow-release fertilizer increased. Compared with CK and chemical fertilizer treatment alone, wormcast treatment could significantly increase the yield of mulberry leaves and the content of crude protein, soluble sugar and crude fat of mulberry leaves[12].

3.3 Study on the principle of earthworm improving soil structure and function The principle of improving soil structure and function by earthworms is essentially the close connection and interaction between earthworms and soil microorganisms. For example, earthworms and AM fungi, which are in different trophic levels and have no direct predator-prey relationship, play a synergistic role in promoting plant growth and improving soil fertility. Earthworms can play a positive role in AM infection by increasing the availability of nutrients, and can significantly improve the mycorrhizal infection rate. Earthworms can also provide more carbon sources for mycorrhizal fungi by promoting the increase of plant biomass, which is beneficial to the development of extra-root hyphae. In the experiment of adding EM bacteria and earthworms to contaminated soil carried out by Dong Weihua *et al.* [13], the mass ratio of organic matter, nitrogen and phosphorus in contaminated soil of the experimental group with addition of EM bacteria changed greatly after being treated by earthworms, that is, earthworm activity could improve the availability and decomposition rate of elements in contaminated soil, which was beneficial to the transformation of nitrogen and phosphorus into plant available state. Li Huan *et al*.[14] studied the interaction between earthworms and mycorrhiza and its effects on corn's absorption of nitrogen and phosphorus in soil. The interaction between earthworms and mycorrhiza increased the biomass of aboveground and underground parts of corn, and the absorption of nitrogen and phosphorus increased the content of carbon and nitrogen, *etc*. in soil microbial biomass. Zhou Dongxing *et al*.[15] studied the degradation effect of polyacrylamide in soil by the synergistic effect of earthworms and bacteria, and found that whether only earthworms or bacteria were added, or both earthworms and bacteria were added, it could significantly promote the degradation of PAM in soil and the synergistic effect of earthworms and bacteria on the degradation of PAM in soil was the best. The bioturbation of earthworms in soil made the soil mix continuously, which was conducive to the spread and diffusion of microorganisms and increased the chance of contact between microorganisms and pollutants.

4 Conclusion

Greenhouse cultivation is an irreplaceable production mode to effectively improve unit output value under the condition of land shortage, but the deterioration of soil quality caused by greenhouse cultivation restricts the sustainable development of this production mode. The combination of earthworms and biological agents can improve the environmental quality of soil in greenhouse cultivation and improve the quality of crops. Mature soil remediation technology with earthworms and biological agents will be widely used and popularized in highly intensive agriculture and forestry practice, so as to better improve the social benefits of intensive production.

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