# Effects of Continuous Cropping on Soil Microbial Flora and Research Progress of Continuous Cropping Obstacle Reduction Techniques

**Qingmei LI, Zebin CHEN*, Yue YAN, Shengguang XU, Zhiwei FAN, Li LIN, Song JIN, Tianfang WANG, Zaixiang ZHU**

College of Agronomy and Life Sciences, Kunming University, Kunming 650214, China

**Abstract** Continuous cropping can bring economic benefits in a short time and meet the growing demand of agricultural products such as grain, but long-term continuous cropping will accelerate soil degradation, lead to the reduction of crop yield and the increase of disease rate, and destroy the balance of soil microbial structure. Therefore, it is not conducive to the sustainable development of soil ecosystem. In this paper, the problems caused by continuous cropping, such as imbalance of soil microbial flora, decrease of biodiversity, accumulation of root exudates and their effects on soil fertility and crop growth, were summarized, and some measures were suggested to alleviate the obstacles of continuous cropping, such as reasonable rotation, adjustment of intercropping planting mode and application of biological fertilizers. Moreover, the paper also looked forward to the development trend of continuous cropping obstacle reduction techniques, including the integration and application of biological techniques, the promotion of green ecological techniques and the application of intelligent management system. This study provides theoretical basis and technical support for the research of continuous cropping obstacle reduction techniques and promote the healthy and sustainable development of modern agriculture.

**Key words** Soil; Microorganism; Continuous cropping obstacle; Reduction technique; Soil improvement

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Soil plays a key role in life gestation and communication. It supports the survival of plants and microorganisms and make them closely linked[1]. Rhizosphere is an active area of microorganisms, and plant root exudates are the driving factors of microbial food and activity. In soil microecology, plants provide nutrients for microorganisms, and microorganisms affect plant growth by changing soil nutrients[2]. Microbial flora structure affects soil material circulation and ecosystem stability, and beneficial rhizosphere microorganisms can reduce pest infection[3], help resist intrusion[4] and improve the environment[5]. Microbial metabolism affects the effectiveness and solidification of soil elements[1]. Soil microbial community is the key to maintaining the stability and health of soil ecosystem. Its composition and activity reflect the strength of fertility, affect the balance and stability of ecosystem, and play an important role in plant nutrient cycle, soil pollutant degradation and promotion of the material and energy flow of ecosystem.

Continuous cropping refers to the continuous planting of crops of the same kind or family in the same plot. In the short term, it can improve the land efficiency, and in the long term, it will easily lead to the imbalance of microbial flora, the deterioration of physical and chemical properties, the aggravation of pests and diseases, the weakening of plants and the decline of yield and quality, thereby seriously affecting the sustainable development of agriculture[6]. At present, the research on continuous cropping obstacles at home and abroad mainly focuses on soil nutrients, physical and chemical properties, microbial species diversity, allelopathy and autotoxicity of crops[7-8]. However, the deterioration of soil physical and chemical properties, the decline of microbial diversity and allelopathy are the main causes of continuous cropping obstacles[9]. At present, continuous cropping obstacles seriously affect the sustainable development and utilization of soil and the safe production of food. It has been found that continuous cropping has a significant impact on microbial community structure, and the root of continuous cropping obstacle is that the structural balance of biological flora in soil ecosystem is broken. Therefore, scholars at home and abroad deeply explore the evolution law of microbial flora in continuous cropping soil and the influence of continuous cropping on microbial flora, find out the dominant functional flora in soil microbial community, and introduce specific functional flora and beneficial flora accordingly, so as to maintain the balance and recovery of the original microbial community and prevent the increase of pathogenic bacteria, which is of great significance for effectively reducing the obstacles of continuous cropping. At present, research on the reduction of continuous cropping obstacles has become the focus of the healthy development of agriculture. In this paper, the problems caused by continuous cropping, such as imbalance of soil microbial flora, reduction of biodiversity, accumulation of root exudates, and the research progress of continuous cropping obstacle reduction techniques, were comprehensively

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Qingmei LI (2002 - ), female, P. R. China, major: horticulture.

* Corresponding author.

discussed, aiming to provide theoretical reference for the healthy production of agricultural soil environment.

## Harm of Continuous Cropping Obstacles

Continuous cropping of crops is harmful. First of all, it will cause the imbalance of soil nutrients, which is because certain nutrients needed by some crops are excessively consumed, and the proportions of nutrients in the soil are out of balance. Secondly, it will lead to the aggravation of pests and diseases, and increase the difficulty and complexity of prevention and control because of the continuous accumulation of pathogenic bacteria and pests in the soil. Furthermore, it will cause the imbalance of soil microbial community structure, mainly manifested in the decrease of beneficial microorganisms and the increase of harmful microorganisms, which will disturb the normal function of soil ecosystem. Meanwhile, it will lead to the deterioration of soil physical properties, such as hardening, poor soil permeability and significant decline in water and fertilizer retention capacity. Moreover, it also produces autotoxicity due to the accumulation of substances secreted by crops that inhibit their own growth in the soil[10]. This series of problems are intertwined and influenced each other, which leads to a sharp decline in crop yield and obvious deterioration in quality[11]. In addition, farmers may even have to overuse chemical fertilizers and pesticides to increase crop yield because of continuous cropping obstacles, which not only increases production costs, but also causes serious pollution and damage to soil, water and air, destroys ecological balance and threatens the sustainable development of the entire agricultural ecosystem.

## Causes of Continuous Cropping Obstacles

### Changed physical and chemical properties of soil

The healthy growth of plants depends on the specific steady-state environment, and healthy underground roots and good soil ecological environment are necessary conditions for the lush growth of the aboveground part. Studies have shown that the change of soil physical and chemical properties will cause continuous cropping obstacles. Long-term single continuous cropping of the same crop will reduce soil pH value, element imbalance and acid-base imbalance[12]. For example, the cation exchange capacity decreased after continuous planting of *Trichosanthes kirilowii*[13] for four years, and the continuous cropping of strawberries[14] caused salt damage. In agricultural production, excessive use of chemical fertilizers is the key factor, which will lead to soil acidification and secondary salinization, weaken the ability of soil to adsorb and exchange cations, and reduce enzyme activity and the content of trace elements[15], which will further lead to nutritional imbalance and decline in disease resistance, aggravate soil-borne diseases and affect the stability of the ecosystem.

### Destroyed balance of soil microorganisms

The key to continuous cropping obstacles lies in the imbalance of microbial community structure in rhizosphere soil, which is manifested by the decrease of bacteria/fungi ratio, the decrease of beneficial bacteria and the increase of pathogenic bacteria. Long-term continuous cropping will reduce the ratio of bacteria to fungi in soil ecosystem[16], and different cultivation methods will cause changes in microbial community, and the metabolites secreted by roots will increase under continuous cropping system[17], which will break the balance of soil microbial flora. Soil formation depends on microbial interaction[18], and the change of microbial population ratio is closely related to continuous cropping obstacles. For example, phenolic acids in the soil with continuous cropping of *Panax notoginseng*[19] will promote the growth of pathogenic bacteria and lead to microbial community disorder.

### Autotoxicity of root exudates

When plants grow, there are leaching and root system secretion behaviors, and the metabolites or harmful components produced inhibit the growth of crops in the same season or in the subsequent period, that is, autotoxicity[20]. Common autotoxic substances are mostly phenolic acids, which are an important factor for continuous cropping obstacles. Autotoxicity is selective and specific[21-22]. Autotoxic substances are mostly dose-dependent, and the higher the concentration, the more obvious the autotoxicity. And they show the characteristics of promoting at low contents and inhibiting at high contents. The combined effect of various toxic substances exceeds the sum of individual effects, and there are three forms: synergy, addition and antagonism. The chemical components of self toxic substances may have certain effects in plants' response to long-term water stress[23], and environmental changes have a significant impact on them.

## Effects of Continuous Cropping on Soil Microbial Flora

### Decreasing species and quantity of microorganisms

Long-term continuous cropping has significantly reduced the types of microorganisms in the soil, especially important beneficial microorganisms, the quantity of which is greatly decreasing. The study of Guan *et al.*[24] pointed out that specific pathogenic bacteria such as *Fusarium* were gradually enriched in the continuous cropping soil of *Curcuma wenyujin*, while the quantity of beneficial microorganisms such as *Bacillus* decreased. Zhen *et al.*[25] found that with the continuous cropping years of strawberry increasing, the species and quantity of beneficial microorganisms, bacteria and actinomycetes in soil decreased gradually, while the species and quantity of soil fungi increased obviously. One of the important reasons for continuous cropping obstacles is that the microbial community structure in rhizosphere soil is unbalanced, while the ratio of bacteria to fungi decreases, the quantity of beneficial bacteria in soil decreases and the quantity of pathogenic bacteria increases. Studies have proved that long-term continuous cropping will lead to the decrease of bacteria/fungi ratio in soil ecosystem[26]. The quantity of some potential pathogenic bacteria, such as fungi, may increase due to the decrease of environmental pressure, which further aggravates the imbalance of community structure. Such unbalanced state not only weakens the self-regulation

ability of soil, but also provides a hotbed for the outbreak of soil-borne diseases.

**Changing diversity and richness of microorganisms**

Wang *et al.* [27] studied the response of soil fungi in flue-cured tobacco to continuous cropping, and found that continuous cropping significantly increased the richness and diversity of soil fungi community. The study of Ruan *et al.* [28] showed that under the condition of continuous cropping of cassava for many years, the richness of soil bacteria increased, but the diversity decreased, and fungi were the opposite. These changes show that the deterioration of soil microenvironment caused by continuous cropping is not conducive to the survival of most beneficial microorganisms, but beneficial to the reproduction of pathogenic bacteria. This trend breaks the natural balance of soil microbial community, and destroys the original harmonious symbiotic microbial community structure. Meanwhile, a recent study showed that under the continuous cropping system, the metabolites secreted by crop roots increased, which potentially promoted the increase of pathogen abundance and diversity. Also, the quantity and species of antagonistic beneficial bacteria are also decreasing, and the change of microbial diversity leads to the destruction of soil microbial flora balance and the change of soil microenvironment structure. These changes significantly affect the ecological function of soil and restrict the normal growth and development of crops in continuous cropping mode, indicating that the changes of soil microbial diversity and community structure are closely related to continuous cropping obstacles.

**Changing dominant microbial community**

Long-term continuous cropping significantly changed the dominant flora structure in soil. The study of Zheng *et al.* [29] showed that the relative abundance of Actinobacteria, Proteobacteria and other bacteria in tobacco continuous cropping soil changed significantly with the increase of continuous cropping years, and the changes of Basidiomycota and other fungi could not be ignored. In addition, *Fusarium*, *Ralstonia* and other pathogens occupied a dominant position in continuous cropping soil, and the balance of soil microbial community was broken. Zhou *et al.* [30] studied the effects of different continuous cropping years on the number of microorganisms in tomato rhizosphere, and found that the quantities of bacteria and actinomycetes in tomato rhizosphere soil decreased and the quantity of fungi increased with the increase of continuous cropping years. Li *et al.* [31] analyzed the soil micro-ecological characteristics of *Rehmannia glutinosa* under continuous cropping, and pointed out that continuous cropping led to the decrease of bacteria in rhizosphere soil, the increase of fungi and actinomycetes, and the transition of soil microbial types from bacterial type to fungal type. All the above cases show that continuous cropping has broken the balance of soil microbial flora.

**Degradation of microbial function and impact on soil fertility**

Continuous cropping will not only lead to the degradation of soil microbial function, and the decrease of soil enzyme activity and nutrient conversion efficiency, but also affect soil fertility. The studies by Zhou *et al.* [30] and Wang *et al.* [32] showed that the activities of catalase, polyphenol oxidase and protease in eggplant rhizosphere soil decreased with the increase of continuous cropping years. Because soil enzymes are important products of microbial activity, their activity directly reflects the rate and intensity of soil biochemical reaction, so the decrease of enzyme activity means that the decomposition rate of organic matter in soil is slowed down and key processes such as nutrient circulation are blocked, which further affects the maintenance and improvement of soil fertility. Meanwhile, the proportion of bacteria and actinomycetes in eggplant rhizosphere decreases and the proportion of fungi increases due to continuous cropping. Such transformation from bacterial soil to fungal soil is a sign of soil fertility failure. The decline of nutrient conversion efficiency makes it difficult for crops to obtain sufficient nutrients from soil, which ultimately affects crop growth and yield. This chain reaction not only damages the sustainability of agricultural production, but also poses a threat to the long-term health of soil ecosystem.

## Reduction Techniques of Continuous Cropping Obstacles

The reduction techniques of continuous cropping obstacles aim to solve the problems of soil environment deterioration and crop growth inhibition caused by continuous cropping. Their development status covers a variety of strategies[33-34], such as soil fumigation technique, which can kill pathogenic microorganisms but has environmental hazards, and scholars are looking for alternatives. Microbial agents can be applied to improve soil by beneficial microorganisms. Rotation and intercropping can break the disease cycle, improve soil and increase biodiversity. Soil physical and chemical properties, soil structure and ecology should be improved. And precision agricultural techniques are also explored to monitor and manage through information techniques. In the future, environmental protection and ecological balance will be more important, and more innovative solutions are expected to be introduced.

**Optimization and application of soil fumigation technique**

Soil fumigation is one of the effective means to alleviate the obstacles of continuous cropping, and it is continuously optimized. Soil fumigants refer to a type of pesticides that is applied to the soil to poison harmful organisms through the gas generated during volatilization and prevent soil-borne diseases, insects, weeds and other hazards in an artificially closed space. Fumigating agents have four advantages. First, it has strong penetration and wide coverage[34]. Second, the field of prevention and control is broad. Third, it has the effect of promoting the increase of yield[35-36]. Fourth, it has quite high efficiency. At present, the main soil fumigants are the following nine kinds[37], namely, dazomet, allyl isothiocyanate, sulfuryl fluoride, lime nitrogen, metham, dimethyl disulfide, methyl iodide and chloropicrin. Jin *et al.* [38] compared the mitigation effects of different soil fumigants on continuous cropping obstacles of muskmelon in greenhouse, and found that

dazomet fumigation could significantly reduce the quatity of pathogenic bacteria and promote the reproduction of beneficial microorganisms. However, it is worth noting that traditional fumigants have certain environmental pollution risks. In order to realize the sustainable development of agriculture and reduce the adverse effects on the ecological environment, the application research of new environmental protection fumigants, such as ozone and ultraviolet rays, is gradually deepening, striving to minimize the environmental impact while ensuring the fumigation effect, aiming to seek a greener and more efficient solution to the obstacles of continuous cropping.

**Diversification and precise application of microbial agents**

Using beneficial microorganisms to inhibit continuous cropping obstacles has become an important research direction. Beneficial microbial agents can improve soil microbial balance through various mechanisms, such as competitive elimination of pathogenic bacteria, biodegradation of harmful substances and improvement of crop immunity[39]. In recent years, with the continuous progress of microbial technology and synthetic biology, the research and development of microbial agents with specific functions has become more diversified and accurate. In the future, with the progress of gene editing and synthetic biology techniques, microbial agents with stronger pertinence and stability will be developed and applied accurately. Microbial agents are widely used in relieving continuous cropping obstacles. Li *et al.* [40] significantly improved the flavor quality of tomato fruit by applying microbial agents. Feng *et al.* [41] found that *Bacillus subtilis* · *Trichoderma harzianum* compound microbial inoculant could significantly reduce the quantity of pathogenic bacteria in the rhizosphere soil of continuous cropping celery and optimize the soil microbial community structure. In a word, microbial agents have performed well in improving the quality of agricultural products, reducing pathogenic bacteria and optimizing soil microbial environment, which has brought new hope and effective ways to solve the problem of continuous cropping obstacles.

**Innovative practice of crop rotation and intercropping mode**

Rotation and intercropping, as traditional agricultural measures, are still of great significance in alleviating the obstacles of continuous cropping. Chen *et al.* [42] pointed out that *Polygonatum sibiricum* rotation could significantly optimize the microbial status of continuous cropping soil of *Panax notoginseng* and reduce the quantity of pathogenic bacteria. Hu *et al.* [43] found that the two planting patterns of sweet potato, namely, rotation with wheat and intercropping with maize, could improve the soil microbial community structure and enhance the diversity of microbial functions. In addition, the study of Wang *et al.* [44] showed that after intercropping or rotation of *Sesamum indicum* L. with wheat, the physical and chemical properties of soil were changed, and the activity of soil enzymes was improved. Moreover, the self-toxicity of soil could be reduced, and the structural composition of soil microbial flora was adjusted, which was beneficial to the growth of *S. indicum* L. in the next crop. In the future, with the in-depth understanding of crop growth mechanism and soil microbial interaction, more efficient and environmentally-friendly crop rotation and intercropping models will be explored and applied.

**Comprehensive application of soil improvement measures**

Soil improvement measures are effective ways to alleviate the obstacles of continuous cropping, such as applying organic fertilizer and biochar, *etc.*, and if various means are comprehensively used, the effect will be better. Li *et al.* [45] reported that different soil improvement methods had different effects on continuous cropping soil of strawberry, so it is necessary to make appropriate choices according to specific actual situation. Because of the excellent pore structure and excellent adsorption performance of biochar, it can effectively improve soil ventilation, enhance water-holding capacity and fix harmful substances. Wang *et al.* [46] found that the effect of biochar combined with soil improvers on acidic soil was very significant, and the best effect was achieved by combined application with algal chitin refined potassium, which could effectively improve the quality and yield of flue-cured tobacco. Pu *et al.* [47] pointed out that different improved materials had certain effects on the growth of continuous cropping *Scutellaria baicalensis* Georgi and the activity of soil enzymes, especially the treatment of earthworm manure and biochar.

Zhang *et al.* [48] reported that biological fertilizers and organic fertilizers could improve the properties of continuous cropping soil in peach cultivation, effectively promote the growth of peach seedlings, and significantly enhance the diversity of bacterial communities. Chen *et al.* [49] found that the combination of soil improvers and interplanting could effectively improve soil physical properties when improving red soil in orange orchards. It could not only improve soil pH value and organic matter content, soil total content and available nutrients, but also reduce soil active aluminum content, and simultaneously reduce soil erosion and improve citrus quality. These studies have jointly constructed the knowledge system of soil improvement and crop growth promotion, and with the progress of understanding and technology, the comprehensive application will be more extensive and efficient in the future.

Numerous studies have shown that soil improvement measures are of great significance for alleviating continuous cropping obstacles and promoting crop growth. Different improvement methods have different effects under different crops and soil conditions. For example, biochar can improve soil physical and chemical properties; organic fertilizers and biological fertilizers can enhance microbial diversity; and the comprehensive application and innovative combination of various modifiers have outstanding performance in soil improvement of different crops. In the future, with the deepening understanding of soil improvement and the progress of related technologies, comprehensive and efficient improvement methods will be more widely used.

## Conclusions and Prospects

To sum up, the impact of continuous cropping on soil microbial flora and the obstacles caused by continuous cropping are

important challenges facing the sustainable development of agriculture at present. Continuous cropping not only accelerates soil degradation, destroys the balance of soil microbial structure, but also significantly reduces soil fertility and increases the occurrence of crop diseases and insect pests, thus affecting crop yield and quality. In order to effectively alleviate the obstacles of continuous cropping, a variety of continuous cropping obstacle reduction techniques have been applied, including the optimization of soil fumigation, the diversified and precise application of microbial agents, the innovative practice of crop rotation and intercropping mode and the comprehensive application of soil improvement measures. The application of these techniques has effectively improved the soil environment, promoted the recovery and balance of soil microbial community, and thus improved the growth status of crops.

Looking forward to the future, with the continuous development of biotechnology and the in-depth promotion of green ecological concept, continuous cropping obstacle reduction techniques will pay more attention to environmental protection and ecological balance. The integration and application of biological techniques, the popularization of green ecological techniques and the introduction of intelligent management system will provide more innovative solutions for solving the obstacles of continuous cropping. Through in-depth study of the interaction mechanism between soil microorganisms and crops and optimization of planting patterns and management measures, it is expected to realize the sustainable development of agricultural production and ensure food security and ecological environment health.

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