Analysis of Soil Fertility and Biological Changes under Long-term Conservation Tillage

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Abstract Compared with traditional tillage, the farmland soil ecosystem realizes increase in the number and diversity of soil microorganisms and animal communities. The conservation tillage measures such as no-tillage (zero tillage) and covering the farmland with organic matters reduce the disturbance to the soil, increase the accumulation of soil organic matter, and provide an excellent microhabitat for the biological activity of the soil. Soil organisms are closely related to soil nutrient movement. Soil animals, soil microorganisms and soil enzymes secreted by them are widely involved in the conversion process of organic matters and mineral nutrients, and they also play an important role in the effectiveness of nutrient utilization. Studies have shown that long-term conservation tillage is favorable for improving the soil biological activity, improving the soil health, and increasing the fertilizer utilization efficiency and the conservation in soil.

Key words Conservation tillage, Soil organisms, Soil fertility

1 Introduction

Soil is a living and dynamic ecosystem. Its composition includes water, air, various inorganic minerals, and organic matters and living organisms. Soil organisms consist of a large number and variety of soil microorganisms, soil animals and lower plants. As a driving force for the decomposition and transformation of foreign organic matter, the soil biological activity is also the driving force for the transformation of organic matter in the soil and the evolution and maintenance of physical structure. It includes soil microorganisms, soil animals, and a series of soil biochemical and physical actions they promote. The degree of ripening of the soil plays an important role in promoting the benign circulation of soil ecology[1]. The diversity of soil microorganisms, soil fauna, and soil enzymes is an important biological indicator for evaluating the soil fertility level. In farmland soil, human beings affect the activity and diversity of soil organisms through different farming practices. Compared with conventional tillage, the conservation tillage technique can reduce tillage, increase surface coverage, achieve "less soil moving" and "less exposing", and realize "moderate moist" and "moist rough" soil state, which plays a unique ecological and economic role in improving the soil environment[2-3]. Research on soil biological changes under the conservation tillage mode can specifically describe the process of conservation tillage to improve farmland ecological environment through biological effects.

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2 Connotation of conservation tillage

2.1 Comparison of conservation tillage and traditional tillage The purpose of tillage is mainly to loosen the soil, remove weeds, and bury fertilizers to create good conditions for crop growth. For example, plowing can turn the crop residues, weeds, and fertilizers on the surface into the soil and clean the surface of the tillage layer; rotary tillage can chop the soil, and create flat and fine seed bed; harrowing can form soft and loose soil layer, cut off the capillary tube in the soil, reduce the water evaporation, so as to play a role of drought protection and moisture maintenance. At the same time, the traditional tillage destroys the protection of the crop residues on the ground, leading to the intensification of soil erosion and wind erosion, and reducing the number of microorganisms and earthworms in the soil, consequently leading to the soil slowly losing its activity. The greater the intensity of tillage, the larger soil deviation from the natural state, and the more the nature itself loses its protective function and nutrient recovery function. In consideration of the farmland soil protection, to reduce soil erosion, wind erosion and water erosion, foreign countries developed the conservation tillage technology in the 1930s. At present, the conservation tillage technology refers to the application of less tillage, no-tillage, and chemical weeding techniques to ensure that crop residues covering the ground surface as much as possible, and to reduce soil erosion and wind erosion, and to achieve sustainable agriculture, on the premise that seed germination can be guaranteed[4]. Based on the principle of reducing the destruction of soil systems and considering the maintenance of relatively high yields with lower energy consumption and material inputs, it is a form of sustainable agriculture with ecological protection significance[5].

2.2 Technical system of conservation tillage Mechanized conservation tillage designs four basic operations, to complete the straw coverage, reduce tillage and control weeds.

(i) Straw coverage and surface treatment operation. After harvesting, straw and residues are left as coverage on the surface, and they are the key to reducing soil erosion and inhibiting blowing sand. Therefore, it is required to keep the straw on the surface as much as possible, and to reduce the destruction to the coverage during the land preparation, sowing, weeding and other operations.

(ii) No-till fertilization sowing operation. Unlike the traditional tillage, the less or no-tillage fertilization sows seeds and fertilizers in soil covered by straws, but it needs support of no-tillage sowing machine. After harvesting, direct sowing is carried out without any tillage, harrowing or shallow loosening. For no-tillage sowing, it needs application of chemical fertilizers in deep layer, and proper repression after sowing.

(iii) Weed and pest control operation. Under the conservation tillage conditions, weeds and pests are relatively easy to grow. Thus, it is necessary to spray crop herbicide, and conduct mechanical or manual weeding one time every crop season. Pests and diseases mainly rely on pesticide seed dressing, or spraying insecticides when pests and diseases occur.

(iv) Deep tillage operation. Conservation tillage relies mainly on crop roots and earthworm to loosen soil. However, due to the compaction of soil by equipment and human beings and animals during operation, some soil still needs loosening one time every 2 – 4 years according to actual circumstance. For newly adopted conservation tillage parcels, a deep loosening should be performed first to break the plow sole. The deep loosening machine should be equipped with a repression device that functions as joint connecting and ground leveling. Deep loosening is carried out under the condition that the surface is covered by straw, and it is required that the deep loosening machine has a strong anti-blocking capability.

Conservation tillage is a basic technology at the technical level of tillage and it also requires a series of suitable supporting technologies. As a mechanized agricultural practice, conservation tillage requires the systematic, standardized, and serialized technical mode. The conservation tillage technical mode should be a technical system that guides a production cycle or a year's operations, rather than only considering one type of crop or one operation. The unity of row spacing and width of the same crop in the same type of area complements the standardized and serialized equipment production, while the standardized and serialized equipment production is closely connected with the improvement of equipment quality and reduction of equipment cost.

3 Farmland soil organisms

Soil is one of the most important habitats for living organisms. It contains abundant species of life. At the same time, the soil ecosystem is a hidden and microscopic ecosystem. Most soil organisms are not visible to the naked eyes. Soil animals and soil microorganisms occupy a certain ecological niche in the soil, and they are closely related to each other. Various organisms together promote the material transformation and energy flow of the soil[6]. The number and type of organisms in the soil can be used to characterize the exuberance of metabolism in the soil. Generally, the soil organisms can be categorized according to body size[7], as listed in Table 1.

Table 1 Statistics of types of known soil organisms

Types	Classification of body size	Number of species
Microorganism	Bacteria and archaea	3 200
(1 – 1 000 μm)	Fungus	Approx. 35 000
Microfauna (< 1 mm)	Protozoa	1 500
	Nematodes	5 000
Medium-sized soil animals	Mites	Approx. 30 000
(1 – 10 mm)	Collembola	6 500
	Diplura	659
	Symphyla	160
	Pauropodina	500
	Enchytraeidae	> 600
Large soil animals	Root-feeding insects	Approx. 40 000
(>10 mm)	Diplopoda	10 000
	Isopoda	2 500
	Termites	2 000
	Ants	8 800
	Earthworms	3 627

3.1 Soil microorganisms Most of the microorganisms in the soil are saprophytic or facultative saprophytic, so soil nutrient content affects the distribution of microorganisms. The climate varies throughout the year, soil properties change, so the microbial activity also changes[1]. The number and types of bacteria, actinomycetes and fungi have vertical distribution, seasonal dynamic change, and regional distribution in the soil profile. Generally, in the soil with higher degree of maturity and fertility level, the changes of decline in microbial diversity are obvious with the deepening of soil profile.

In well ventilated soil, bacteria and fungi take absolute predominance, while in soil with little or no oxygen, bacteria perform almost all biochemical reactions and actions, and bacterial have the ability to grow rapidly and can rapidly perform decomposition, thus bacteria play an outstanding role in the soil. The fungus is suitable for a wide range of pH. Therefore, in an acid environment that is not suitable for the growth of bacteria and actinomycetes, fungi account for a large proportion. Filamentous fungi are highly aerobic, so most of the fungi accumulate on the surface of the soil, while waterlogging or severely humid environment will limit their activity. The main activity of filamentous fungi is the degradation of complex molecules such as cellulose and lignin. Actinomycetes usually undergo aerobic metabolism, which is more tolerant to drought and suitable for alkaline environment. The growth and development of actinomycetes are much slower than that of bacteria and fungi. In terms of ecology, actinomycetes can secrete antibiotics and exert antagonistic effects on bacteria and fungi, which to a certain extent can control the composition of soil microbial populations.

3.2 Soil animals A soil animal is an animal that has regularly spent a period of its life in the soil and has a certain influence on the soil. The soil animal covers a wide range of species, including almost all terrestrial invertebrates. Nematodes, oligochaeta, ticks and mites and collembola are important groups in agriculture. The nutrition of soil animals is mainly plant feeding, and there are few predatory soil animals. Using plants and their residuals as the main food source is the characteristics of farmland soil animals, reflecting the adaptation of soil animals to farmland ecosystems[8].

The distribution of soil animals has obvious regional characteristics. The number of soil animal groups is smallest in high latitude and cold regions, and largest in tropical and subtropical regions. The number of soil animals is closely related to the accumulation of organic matters in the soil and generally increases with the increase in soil organic matter content. Both the soil water content and soil temperature affect the composition and distribution of soil animals. In well-developed and undisturbed soil, the composition and number of soil animals present clear layers and generally show a decreasing trend as the soil level deepens. Soil animal is an essential part of the soil ecosystem. In the biological cycle of the ecosystem, it plays an important functional role in the conversion, storage and release of nutrient elements[9].

4 Relationship between soil organisms and soil fertility

4.1 Relationship between soil microorganisms and humus Without the activity of microorganisms, there will be no fertile soil. According to estimation, the highest microbial content in the soil is up to 0.5 – 0.7 t/ha. In the soil, microorganisms are not only large in number but also the most easily changing part of the organisms. Decomposition products of microorganisms after the death will become the humus of the soil.

The formation of soil humus is a long-term process. Microorganisms play an active role in the conversion of fresh organic matter into humic acid and renewal of humus. In the conversion process of organic matters, there are two major types of microorganisms involved in activities, one is fermenting microorganism, which decomposes fresh organic matters to form humus, and the other group is an indigenous microorganism which mainly mineralizes humus. The dominant species of these two major groups of organisms are constantly changing with the decomposition of organic matters, the formation of humus, and the re-decomposition.

4.2 Relationship between soil microorganisms and mineral nutrients Microorganisms are important nitrogen pool and transfer station for plant nutrition. The biological fixation of nitrogen by microorganisms is of great significance in reducing the loss of nitrogen in the soil. Besides, microorganisms participate in the conversion of nitrogen compounds: in dryland soil, organic matters, ammonium nitrogen, and amide nitrogen are eventually converted by microorganisms into nitrate nitrogen for crop absorption and utilization. Microorganisms that decompose phosphorus compounds: 30% to 50% strains of molds have phytase activity and can decompose phytic acid or phytochemicals into phosphate and inositol. Many microorganisms in the soil generate multiple organic acids (such as citric acid), which can promote the dissolution of poorly soluble phosphate[10].

4.3 Relationship between soil animals and soil fertility In the agricultural ecosystem, soil animals participate in the decomposition and mineralization of soil organic matters with their enormous biomass, and the loss of mineralized material is slowly released throughout the plant growth season. Such biological regulation process plays a functional role in the agricultural ecosystem. In addition, soil animals exert a biological and energetic effect on the microbial community, and through their own movements and feeding behavior, they promote the formation of soil humus and granule structure, increase water permeability and aeration, improve the physical and chemical properties of soil, which is conducive to the improvement in the productivity of agricultural ecosystem.

The ecological functions of soil animals mainly include bioturbation and organic matter decomposition. Bioturbation is manifested in the loosening and mixing of soils. For example, large soil animals, such as earthworms, ants, and termites, have an important influence on the transport of air and water in the soil. They not only change the structure of the soil, porosity, aeration, and hydrothermal conditions by creating channels in the soil, and improve the micro-environment for the survival and reproduction of other smaller soil animals, so they play an important role in maintaining the soil structure. Decomposition of organic matter is reflected in the comminution of plant residues and their combined decomposition with microorganisms; carcasses of soil animals can be decomposed by microorganisms into nutrients necessary for plants.

4.4 Soil enzyme activity as an indicator of soil fertility Soil enzymes refer to the "enzymes isolated from the living body" in the soil, including free extracellular enzymes in soil, enzymes that bind to soil solid components, enzymes in non-proliferating cells, enzymes that are active in dead cells, and enzymes that bind to fragment of dead cells[11]. Soil enzymes are mainly physically or chemically bound to the soil organic and inorganic particles, or complexed with humus, while the enzyme content in the soil solution is very small. The activity of soil enzymes can be used to characterize the conversion or cycling of related substances in the soil: the determination of the activity of soil proteolytic enzymes can reflect the progress of soil nitrogen cycling; the activity of soil phosphatase is related to the effective conversion of phosphorus in soil-containing organic compounds; soil urease activity, to a certain extent, determines the degree of utilization of urea nitrogen by plants; the activity of soil cellulase and other carbohydrases can be used to characterize the decomposition rate of carbon-containing organic matter.

5 Effect of farming measures on soil biological evolution in farmland

5.1 Crop residues covering the field Crop residues are the main source of energy for soil biological activities and also an important part of the biological cycle of farmland soil materials. Besides, as the main food sources for various soil animals, crop residues provide easy-to-use carbon sources for soil microorganisms and promote the growth and reproduction of soil microorganisms. Humic acid produced by decomposition regulates the acidity and alkalinity of soil and is beneficial to the survival of fungi; straw decomposition leaves a large amount of organic matter in the soil, which can stimulate the activity of various soil enzymes. Conservation tillage can significantly improve the living environment of soil organisms through returning, straws to the field and the soil biological activity of such farmland is superior to the traditional non-straw-covered farmland[12].

5.2 No-tillage Microorganisms are very sensitive to soil disturbance. Compared with conventional tillage, no-tillage soils have more abundant and diverse soil microorganisms, nematodes, and arthropods, and can significantly increase the number and activity of soil microorganisms. By contrast, traditional tillage and rotary tillage will reduce the number of animals such as earthworms in the soil. No-tillage coverage has changed the ecological conditions, created a good living condition for soil animals, and also reduced the mineralization of soil organic matters, which is conducive to the accumulation of organic matters.

5.3 Herbicides There have been extensive studies about the effects of various herbicides on soil microorganisms and their enzyme activities, but the results are quite different. In general, after herbicides are applied to the soil, they would show the effect on bacteria and fungi in the first week, but the microorganisms would soon be restored to the control level. The results obtained from different concentration of dryland herbicide trifluralin for soil bacteria, actinomycetes, fungi and azotobacter showed that the growth of bacteria, actinomycetes, molds, and azotobacters was of varying degrees at low concentration, but would show inhibition function after exceeding a certain concentration. The critical threshold is different for different microorganisms to shift from promotion to inhibition.

5.4 Fertilizer application Proper fertilization and use of organic fertilizer for a long term can improve the physical and chemical properties of the soil, and also provide abundant nutrition for plants and soil microorganisms, promote their growth and development, and improve the soil microbial activity[13]. Fertilizers can promote the metabolism of crop roots, increase root exudates, and accelerate the reproduction of microorganisms, so as to facilitate the improvement of soil enzyme activity. For organic fertilizers, apart from promoting root metabolism in crops, they also contain a certain amount of enzymes themselves. Fertilization mainly affects the population density of major taxa in the soil but has little effect on taxonomic diversity.

5.5 Crop rotation The type of plant community preliminarily determines the composition of the microbial community. The diversity of farmland soil microbial population is positively correlated with the diversity of crops covered on the soil[14]. The roots of different crops secrete extracellular enzymes during metabolism and release intracellular enzymes when the crop residues break down; crops can act on different microorganism flora through rhizosphere effects, and crop root exudates stimulate the development of microorganisms, thus the diversity and activity of soil microorganisms and soil enzymes during rotation are higher than that during the continuous cropping[15].

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