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Strategies for Improving the Fertility of Arable Land Soils in China

Hu Yingjie[1], Kong Xiangbin[1], Zhang Yuzhen[2]

1. College of Land Science and Technology, China Agricultural University, Beijing 100193, China
2. School of Public Administration and Policy, Renmin University of China Beijing 100872, China

Abstract: We systematically reviewed the trends in the fertility of arable land soils in China. The results suggested that soil fertilizing methods need to evolve from the simple application of chemical fertilizers to the combined application of organic and inorganic fertilizers; moreover, soil cultivation and preservation should be pursued in parallel to maintain soil fertility, and a spatial differentiation control should be implemented. Additionally, we summarized a series of actions that can improve the fertility of arable land soils in China (e.g., increase the application of organic fertilizers, promote straw returning to the field, resume the promotion of green manure cultivation, improve farming conditions, and optimize the layout of agroforestry networks). At last, we proposed policy suggestions for the implementation of several projects: high-standard farmland construction, soil improvement and restoration, grass-crop rotation, straw returning, and livestock-poultry manure application.
Keywords: arable land; soil fertility; improvement strategy; sustainable use

1 Analysis of fertility change for arable land soils in China

1.1 General soil fertility and regional disparities

The Food and Agriculture Organization (FAO) data shows that the fertility of the arable land soils in China is relatively poor, positioned between those of the mid- and lowest ranking countries of the world (Fig. 1). The average soil organic matter (SOM) content is 18.63 g/kg, corresponding to only 57% of the global average value (32.54 g/kg). Additionally, it is slightly higher than the average SOM content in Central Asia, Western Asia, and Northern Africa, while it is much lower than that in South-East Asia, Northern America, Northern Europe, etc.

According to the second national soil survey in China, the average SOM data regarding cultivated soils were statistically compiled for each province; the results showed great disparities at the regional level [1]. The average cultivated SOM content in the Heilongjiang Province is 37.48 g/kg, more than twice the national average (18.63 g/kg) and nearly four times that of the Shandong Province (Fig. 2).

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Corresponding author: Kong Xiangbin, College of Land Science and Technology, China Agricultural University, professor. Main research field is arable land evaluation and protection. E-mail: kxb@cau.edu.cn
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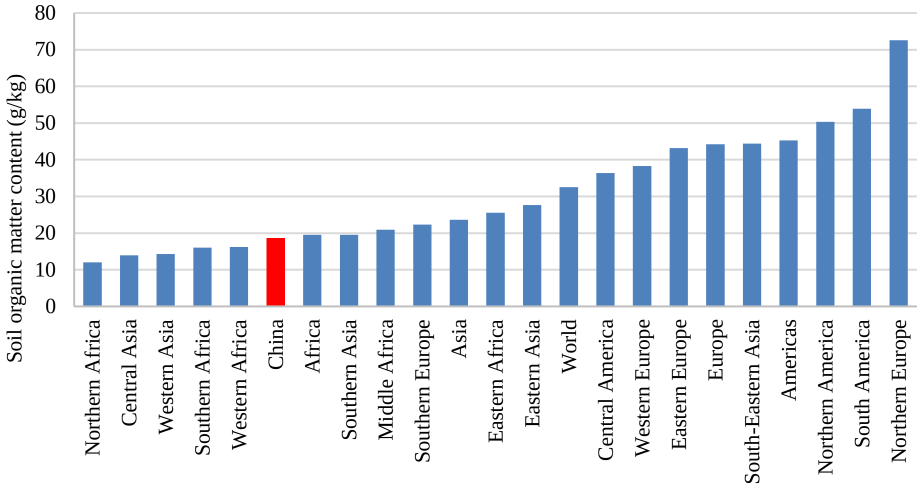

Fig. 1. SOM content of arable land in China and in other regions of the world.

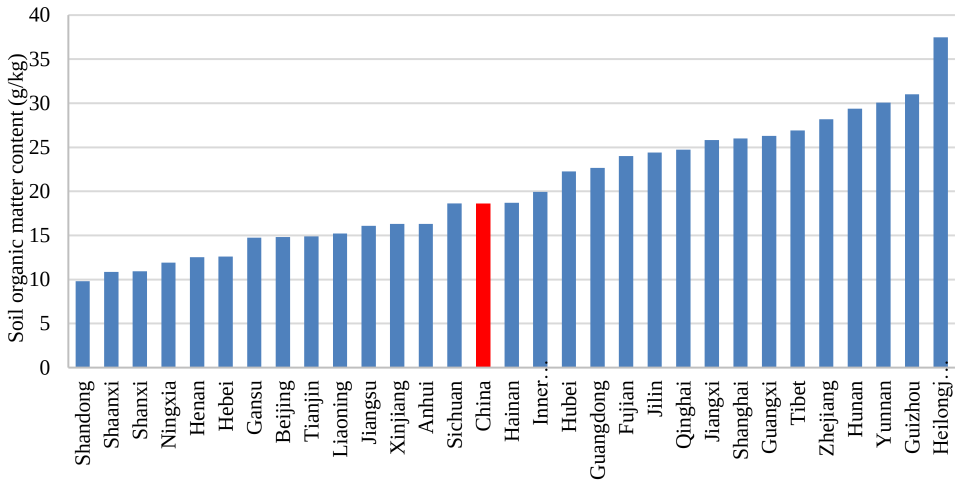

Fig. 2. SOM content of arable land in the provinces of China.

1.2 Changes in regional SOM content of arable land

Nutrient data on the arable land soils were obtained from numerous samples collected all over China (1184 in year 1980, and 574 in year 2010). The nutrient grading criteria for the second national soil survey are shown in Table 1. We analyzed changes in the organic matter content of arable land for the past three decades in nine regions of Northeast China: Huang-Huai-Hai, the middle and lower reaches of the Yangtze River, South China, the Inner Mongolia Plateau and the Great Wall area, the Loess Plateau, Southwest China, Northwest China, and the Qinghai-Tibet Plateau.

Table 1. Soil nutrient grading criteria.

Soil nutrient grade	SOM content (g/kg)
1	>40.0
2	30.0–40.0
3	20.0–30.0
4	10.0–20.0
5	6.0–10.0
6	<6.0

From year 1980 to 2010, the average SOM content of black soil in Northeast China decreased from 41.7 g/kg to 24.4 g/kg (by 17.3 g/kg and two nutrient grades), while that of chernozem decreased by 16.6 g/kg and two nutrient grades. The average SOM content of fluvo-aquic and cinnamon soils in Huang-Huai-Hai area, as well as those of paddy and red soils in the middle and lower reaches of the Yangtze River did not change much, while that of the

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yellow and paddy soils in Southwest China declined by 5.2 g/kg and 4.1 g/kg, respectively, and both decreased by one nutrient grade. The average SOM content of lateritic red soil in South China decreased by 4.0 g/kg and one nutrient grade, while that of latosols and paddy soils remained similar. The average SOM content of cinnamon and cultivated loessial soils in Loess Plateau remained relatively stable, while that of sierozem increased slightly (Table 2).

Table 2. Change in organic matter content for different soil types and different regions, observed between years 1980 and 2010.

Region	Soil type	Average SOM content (g/kg)			Soil nutrient grade		
		1980	2010	Change	1980	2010	Change
Northeast China	Black soil	41.7	24.4	−17.3	1	3	−2
	Chernozem	36.5	19.9	−16.6	2	4	−2
	Baijiang soil	29.5	16.3	−13.2	3	4	−1
	Meadow soil	32.5	31.6	−0.8	2	2	0
Huang-Huai-Hai	Fluvo-aquic soil	13.7	15.7	1.9	4	4	0
	Cinnamon soil	24.3	23.1	−1.3	3	3	0
Middle and lower reaches of the Yangtze River	Paddy soil	27.8	23.4	−4.4	3	3	0
	Red soil	22.1	27.3	5.2	3	3	0
Southwest China	Yellow soil	32.6	27.4	−5.2	2	3	−1
	Paddy soil	31.2	27.1	−4.1	2	3	−1
	Purplish soil	28.1	25.0	−3.1	3	3	0
South China	Lateritic red soil	32.4	28.4	−4.0	2	3	−1
	Paddy soil	27.0	27.2	0.2	3	3	0
	Latosols	26.3	23.5	−2.8	3	3	0
Loess Plateau	Cinnamon soil	25.6	23.4	−2.2	3	3	0
	Cultivated loessial soil	15.5	17.7	2.2	4	4	0
	Sierozem	13.7	20.3	6.6	4	3	1

1.3 Fertilizer application status and soil acidification of arable land in china.

In 2014, the consumption of chemical fertilizers in China was equal to 5.996 × 10^7 tons, accounting for one-third of the world's total. The amount of chemical fertilizers applied per unit of arable land area reached 567 kg/hm^2 [2], the value among the major grain-producing countries, and more than four times the world average. According to the statistical data from the National Agricultural Technology Extension Service Center, the proportion of organic fertilizers in the total amount of fertilizer input in China was less than 10%; their proportion in the field was much lower than that in the United States, Europe, and other countries (40%−60%) [3]. An insufficient input of organic fertilizers and a high input of chemical fertilizers led to the acidification of the arable land, and an inefficient fertilizer absorption-utilization. Since the early 1980s, the average pH value of the cultivated soil in China has decreased by 0.13−0.80; the arable land of southern China were particularly affected by this acidification [4].

1.4 Potential for improvement of fertility in arable land soils

The SOM content for the major arable land soil types in 2010 was compared with that under the optimal fertilization method used in the field experiment; thereafter, the potential for improvement of the SOM content in the arable land was quantified for each region (Table 3). The major soil type in Huang-Huai-Hai was the fluvo-aquic soil. In 2010, its average SOM content was 15.68 g/kg, but it reached 43.20 g/kg under optimal fertilization conditions (when nitrogen and organic fertilizers were combined): the potential for improvement (27.52 g/kg) was relatively high. The SOM content of paddy soil in the middle and lower reaches of the Yangtze River also had a great potential for improvement (18.32 g/kg). The potential for improvement of the SOM content in purple paddy soil in Southwest China was 17.21 g/kg. The SOM content of black soil in Northeast China could reach 56.27 g/kg under the optimal application of nitrogen, phosphorus, and potassium fertilizers combined with "circulating organic fertilizer". The average SOM content in 2010 was 41.71 g/kg and the potential for improvement was about 14.56 g/kg. The potential for improvement of the SOM content in brown soil was relatively small (4.99 g/kg), while those in paddy soil from South China and in gray desert soil from Northwest China were 12.58 g/kg and 11.62 g/kg, respectively. The potential for improvement of the SOM content in cinnamon soil and cultivated loessial soil from the Loess Plateau, red soil from the middle and lower reaches of the Yangtze River and Southwest China, was relatively small.

Table 3. Potential for improvement of the SOM content in the main types of arable land soils.

Region	Soil type	SOM content in 2010 (g/kg)	SOM content under optimal fertilization (g/kg)	Potential for improvement (g/kg)	Type of optimal fertilization
Northeast China	Black soil	41.71	56.27	14.56	N, P and K fertilizer combined with "circulating organic fertilizer" [5]
	Brown soil	25.40	30.39	4.99	N, P and K fertilizer combined with organic fertilizer [6]
Huang-Huai-Hai	Fluvo-aquic soil	15.68	43.20	27.52	N fertilizer combined with organic fertilizer [5]
Middle and lower reaches of the Yangtze River	Paddy soil	24.88	43.20	18.32	P and K fertilizer combined with organic fertilizer [7]
	Red soil	27.29	27.80	0.51	N, P and K fertilizer combined with organic fertilizer [5]
Southwest China	Purple paddy soil	24.99	42.20	17.21	Organic fertilizer [8]
	Red soil	31.17	35.43	4.26	N and P fertilizer combined with organic fertilizer [5]
South China	Paddy soil	27.16	39.74	12.58	N, P and K fertilizer combined with organic fertilizer [5]
Loess Plateau	Cinnamon soil	23.44	29.40	5.96	N, P and K fertilizer combined with organic fertilizer [5]
	Cultivated loessial soil	17.73	19.78	2.05	N, P and K fertilizer combined with organic fertilizer [5]
Northwest China	Gray desert soil	23.60	35.22	11.62	N, P and K fertilizer combined with organic fertilizer [5]

2 Strategies and approaches for improving fertility of arable land soils in China

2.1 Strategies

2.1.1 From single to combined applications of organic and inorganic fertilizers.

To improve the fertility of the arable land soils in China, it is necessary to evolve strategically, from the simple application of chemical fertilizers, to the combined application of organic and inorganic fertilizers. In future, organic fertilizers could potentially constitute more than 40% of the total fertilizers used, based on the following methods: improvement of livestock and poultry manure utilization rate, direct return of crop straw to the field, restoration and expansion of the planting areas of green manure crops, reasonable use of organic nutrient resources, and substitution of chemical fertilizers with organic fertilizers.

2.1.2 Cultivation and preservation should be pursued in parallel to maintain soil fertility.

The use of arable land in China should "contemplate both cultivation and maintenance" to maintain and restore soil fertility, attain a sustainable use of the arable land, and ensure a healthy and sustainable development of agriculture. Grain-fertility crop rotation and intercropping systems should be applied in conformity with local conditions, to maintain and improve both the SOM content and quality. For instance, the grain-grass rotation could be promoted in northern farming-pastoral areas and in the northwestern arid areas, while the grain-cash crop, grain-feed crop, and grain-green manure crop rotation could be implemented in the central and southern regions; additionally, seasonal fallow should be carried out according to the local conditions in groundwater funnel areas where the soil productivity is seriously reduced.

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2.1.3 Use of spatial differentiation control for the improvement of soil fertility

Different management measures should be adopted in different regions to improve the fertility of arable land soils. It is necessary to promote the graded protection of arable land with different fertility levels, evaluate the level of protection for high-quality arable land, and ensure that soil fertility does not decrease with time. Meanwhile, it is also important to improve the fertility of low-quality arable land. In the cases where soil fertility decreased due to long-term overuse, the methods concerning land utilization should be adjusted and anthropogenic pressure should be reduced properly, to promote their recovery. To ensure ecological security and sustainable land use, it is necessary to return some farmlands to forests, grasslands, or wet areas, depending on the local conditions. Overall, to improve the soil fertility, we should adhere to the basic concept of regional cooperation, and take multiple measures according to local conditions.

2.2 Approaches for the improvement of SOM content in China's arable land soils

2.2.1 Combined use of organic and chemical fertilizers

A formulated and balanced fertilization process should be promoted, and organic fertilizers should be applied to regulate soil fertility and increase the SOM content. The major grain production areas in China (Huang-Huai-Hai, the middle reaches of the Yangtze River and the Jianghuai Region, the Sanjiang Plain, the Songnen Plain, and the Sichuan Basin) should be considered key areas for increasing the application of organic fertilizers. More specifically, new technological devices are required for the mechanized production of organic fertilizers, for the improvement of their scientific and technological level, for the realization of an integrated production–storage–transportation–field application cycle of organic fertilizers, and for the realization of practical protocols. Large and medium-sized enterprises, including livestock and poultry farms, should be encouraged in the production of organic manure from waste materials (e.g., livestock and poultry excrement) by providing incentives for their production, transportation, taxation, etc. Agricultural technology service systems should focus on encouraging and guiding ordinary farmers in the application of organic fertilizers in their fields for the improvement of soil fertility.

2.2.2 Promotion of straw returning to the field

The straw returning to the field plays a positive role in reducing the use of chemical fertilizers, while it maintains and improves the fertility of arable land soils. The key technological research in this aspect should be accelerated, focusing on high-horsepower tillage machines, baling machines, and crushers for the northern areas, and on machines suitable for the relatively small paddy fields in the southern areas. Meanwhile, the policies in support of the enterprises focused on the straw-returning machinery production should be improved, and appropriate subsidies should be given to farmers or enterprises which decide to buy and use machinery to return the straw to the fields, in accordance with the local conditions.

2.2.3 Resuming and promoting the cultivation of green manure

Green manure crops can effectively improve soil fertility and provide a source of forage, while they can also partly replace chemical fertilizers, reducing environmental pollution. Thus, the planting of green manure crops should be resumed and expanded according to the local conditions. Alfalfa and feed rape are the appropriate green manure crops for the northern areas, while feed rape, milk vetch, and ryegrass are suitable for the winter fallow fields in the southern areas. The crop rotation pattern can be performed in the areas having one crop per year, while an intercropping pattern can be implemented in the double or triple cropping areas. The scientific research related to the development of green manure should be resumed and further developed, and national green manure research and test systems, as well as seed bases, should be established. The construction of an improved grassroots agricultural technology service system should be carried out, while the scientific knowledge related to green manure should be continuously updated and applied to the practical agricultural production. The green manure planting subsidy should be restored and a unified seed supply should be implemented in the areas where the conditions permit.

2.2.4 Improving farming conditions and optimizing the layout of agroforestry networks

The optimization of farming conditions and farmland forest network layouts can improve the water and soil conditions in arable land, promote biological cycles in the agroforestry ecosystem, and improve the fertility of the arable land soils. In the facility-dependent water-deficient areas, irrigation facilities should be improved to respond adequately to the demand for water resources; on the other hand, highly efficient water-saving technologies (e.g., spray drip, membrane drip, and integrated water-fertilizer irrigations) should be prioritized for the improvement of the water-use efficiency in the resource-based and water-deficient areas. Drainage systems should be improved in flood-prone areas. In mountainous and hilly areas, where soil erosion is frequent, contour planting and terracing should be applied to slow down the thinning trend of cultivated soil layers. In plain and hilly areas where fields are fragmented, farmland remediation should be carried out to improve the farming conditions. In the areas affected by erosion and desertification, the shelterbelt system should be strengthened, to prevent soil fertility degradation.

3 Projects for the improvement of fertility in China's arable land soils

3.1 High-standard farmland construction projects

At present, the proportion of low- and medium-yield fields in China is still high. A considerable amount of prime farmland infrastructure is in poor condition; thus, there is still a great potential for the improvement of the prime farmland quality. It is advisable to continue the implementation of high-standard farmland construction projects. During the 13th Five-Year Plan period, China will ensure the construction of 4×10^8 mu, and strive to build 6×10^8 mu of the high-standard farmland. High-standard farmland construction projects in different regions should have different priorities. Northeast China should focus on improving the farmland water conservation facilities and on protecting the black soil. Huang-Huai-Hai should continue the conversion of saline-alkali lands, of low- and medium-yield fields, and increase the construction of farmland infrastructures. The middle and lower reaches of the Yangtze River should actively manage small watersheds to prevent soil erosion. Southwest China should improve the environmental protection and restoration aspects, and combine effectively the construction of high-standard farmlands with the policy of Grain for Green and desertification control. South China should promote the soil remediation of contaminated farmlands. Northwest China should protect and improve the ecological environments, prevent land salinization, and restrict the exploitation and utilization of land in the ecologically fragile areas.

3.2 Soil improvement and restoration projects

It is advisable to carry out different soil amendment and remediation projects in China, depending on the local conditions. In southern China, soil acidification should be minimized by reducing the chemical fertilizer application and the application of functional organic fertilizers and of soil conditioners that provide minerals should be promoted. Soil acidification in China should be reduced to about 2.99×10^8 mu of arable land. In arid regions such as Xinjiang, Inner Mongolia, and the western Northeast Plain, soil amendment and remediation projects should focus on soil desertification control and salinization treatments. Arable land soils that are undergoing severe desertification should be turned into grasslands. Advanced irrigation technology should be actively promoted to improve the efficiency of water resources. Saline and alkaline lands, where water resource conditions permit, should be improved through the water conservation engineering measures combined with the chemical and biological amendment measures. The areas of arable land requiring soil amendment to treat salinization in the irrigated areas of Northern Yinchuan and Xinjiang correspond to about 2.56×10^6 mu and 2×10^7 mu, respectively. Meanwhile, the prevention and remediation of contaminated farmlands in the sewage irrigation areas and around industrial lands should be promoted. This objective could be achieved by building farmland ecological ditches for the purification of surface runoff and for farmland irrigation and drainage, while carrying out comprehensive treatment of the agricultural non-point source pollution in typical watersheds. The organic and heavy metal pollution in arable land, while building plant isolation belts or artificial wetland buffer zones, should also be controlled efficiently. It is expected that, by 2020, 1×10^7 mu of the contaminated farmland will be reclaimed and rehabilitated in China.

3.3 Grass-crop rotation projects

It is advisable to implement the grass-crop rotation project; key areas would be the Northeast Plain, North China, the northern farming-pastoral area, the northwestern arid region, and the vast southern winter fallow fields. Grain-feed crop (silage-forage) rotation should be carried out in Northeast China; the proportion of forage planting could be about 10%−20%. Grain-cash-feed crop rotation could be implemented in North China. In the farming-pastoral areas, where agriculture is combined with animal husbandry, grain-feed crop (silage-forage) rotation should be implemented; the proportion of forage planting could be 20%−40%. In the northwest arid regions, grain-cash crop (cotton-fruit) and grain-feed crop (silage-forage) rotations should be applied. The proportion of forage grass can be 10%−30% in the agricultural area, but it can be increased up to 50% in the

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pasturing area. Combined grain-cash and feed crop (green manure crop-feed rape) rotations should be implemented in south China, making full use of the winter fallow fields, to produce legume green manures and feed rapes. By 2030, 7 × 10^7 mu of grass-crop rotation could be realized in the north: 4.5 × 10^7 mu in the farming-pastoral area and northwest arid area, and 2.5 × 10^7 mu in Northeast China and North China. In the winter fallow fields of South China, grass-crop rotations, including legume green manures and feed rapes, can be realized in about 1×10^8 mu of arable land.

3.4 Straw returning projects

Based on the comprehensive straw utilization project, the straw returning project should be actively applied. In areas with flat and open topography (e.g., the Northeast Plain and the Huang-Huai-Hai Plain) corn straw deep-returning technology, conservation tillage technology with straw mulched returning, and the "one-stop" operation mode of no-tillage and sowing should be promoted; these actions would effectively improve the farming efficiency and the straw returning rate. However, in the areas with unsuitable conditions for mechanical straw crushing and returning to the field, or for the large horsepower machinery (e.g., southern hilly areas) a technology for the acceleration of straw rotting and livestock-poultry manure fermentation should be researched and developed. Additionally, the return of the straw after composting, or as animal manure, should be promoted to improve the quality of the returning straw. The straw returning rate could be increased by 10%−20% over the present rate of 30%.

3.5 Livestock and poultry manure application projects

It is advisable to apply the fertilizer utilization project on livestock and poultry manure; key areas of application would be Sichuan, Henan, Shandong, Inner Mongolia, and other areas characterized by both, a developed livestock-poultry breeding industry and serious pollution. A special emphasis should be placed on improving the level of safe treatments and the utilization livestock and poultry manure resources. Meanwhile, the most suitable manure fertilizing technologies should be promoted, in accordance with the breeding scale. Large-scale farms should be considered for the accumulation of livestock-poultry manure and for the utilization of reusable systems; small-scale farms should be instead considered for the improvement of waste recycling. Furthermore, it is important to extend the research on fertilizer utilization technologies applicable to livestock-poultry manure, and develop different types of fertilizer products according to the specific types and quantity ratio between the livestock and poultry manure. Finally, it is necessary to extend the research on processing equipment and upgrade the production process to reduce production costs; still, the effectiveness of fertilizers should be ensured, and a large-scale promotion of livestock-poultry manure utilization should be performed.

References

[1] Wang W, Li X B. Study on the marginal productivity of cultivated land with change of soil organic matter in China [J]. Scientia Geographica Sinica, 2002, 22(1): 24–28. Chinese.

[2] Zhang C Q, Wang L, Hua C L, et al. Potentialities of fertilizer reduction for grain produce and effects on carbon emissions [J]. Resources Science, 2016, 38(4): 790–797. Chinese.

[3] Zhu Z L, Jin J Y. Fertilizer use and food security in China [J]. Plant Nutrition and Fertilizer Science, 2013, 19(2): 259–273. Chinese.

[4] Guo J H, Liu X J, Zhang Y, et al. Significant acidification in major Chinese croplands [J]. Science, 2010, 327(5968): 1008–1010.

[5] Xu M G, Zhang W J, Huang S M, et al. Evolution of soil fertility in China (2nd edition) [M]. Beijing: China Agricultural Science and Technology Press, 2015. Chinese.

[6] Luo P, Han X, Yan W, et al. Influence of long-term fertilization on soil microbial biomass, dehydrogenase activity, and bacterial and fungal community structure in a brown soil of Northeast China [J]. Annals of Microbiology, 2015, 65(1): 533–542.

[7] Huang J, Gao J S, Zhang Y Z, et al. Change characteristics of rice yield and soil organic matter and nitrogen contents under various long-term fertilization regimes [J]. Chinese Journal of Applied Ecology, 2013, 24(7): 1889–1894. Chinese.

[8] Wang S M. Relationship between fertilization methods and soil fertility of purplish paddy soil [J]. Journal of Ecology and Rural Environment, 2000, 16(3): 23–26. Chinese.