Progress in Researches on Evaluation of Quality of Cultivated Land Consolidated from Coal Mining Subsided Land

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Abstract The evaluation of consolidated cultivated land quality can provide basic information for how to perfect the program of land consolidation, as well as a reference for the dynamic monitoring of farmland quality in mining area. Based on the consultation and analysis of related literature, we can conclude that: firstly, most scholars focus on soil consolidation, while consider little about land use and economic condition. Secondly, foreign scholars usually use crop yields to judge the success of land consolidation, while domestic scholars have been evaluated the quality of consolidated cultivated land synthetically from several aspects, such as soil fertility, soil environmental quality, and farmland infrastructure conditions. Specifically, most of the evaluations are static, and indicators are different. Besides, the quality of consolidated cultivated land is generally low, and it lacks systematic research on technologies for improving quality of cultivated land consolidated from coal mining subsided land. It is concluded that future researches should focus on establishing scientific and feasible evaluation system to realize comparison of quality change in the dynamic course of "undisturbed - subsided - consolidated" cultivated land in coal mining areas, as well as technologies for improving quality of cultivated land consolidated from coal mining subsided land.

Key words Consolidation of coal mining subsided land, Quality of cultivated land, Evaluation

Coal is the major energy source of China, and 96% of its output comes from underground mining. Excessive exploitation of underground coal resources, stress on overlying rock strata of the gob area becomes unbalanced, the overlying rock strata moves and deforms, which lead to subsidence in various degree. According to relevant statistical data, China' coal mining subsided areas are mainly distributed in eastern grain producing areas, including high-yield capital farmland. Such destruction of large area of high quality cultivated land deteriorates tense situation of large population and little land in mining area, which becomes an outstanding factor influencing regional social stability. Therefore, the consolidation of coal mining subsided area is one of the most important approaches to realize integrated "quantity, quality and ecological" management of cultivated land and sustainable and steady development of social economy. Nevertheless, for a long time, China's land consolidation focuses on quantity, while belittles quality, and the contribution is not high to raising quality level of cultivated land and increasing yield of grains and income of farmers. Quality evaluation of cultivated land for coal mining subsidence land consolidation can provide reference for monitoring quality of cultivated land in coal mining area and for land requisition - compensation balance, and will be helpful for constantly improving land consolidation scheme in mining area, increasing grain yield and improving quality of cultivated land. At present, both domestic and foreign researches focus on soil quality, and there are limited researches on evaluation of quality of consolidated cultivated land. We firstly summarize past researches, find out weak points of existing researches, and make clear direction and key points of future researches.

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1 Progress in foreign researches on evaluation of quality of cultivated land consolidated from coal mining subsided land

Some foreign countries which have developed mining industry have carried out researches on evaluation of quality of cultivated land consolidated in mining areas, but most researches focus on soil quality evaluation. In addition, many scholars believe that changes in physical properties of soil are major factors influencing quality of reclaimed soil. Some scholars evaluate quality of reclaimed soil through combining traditional soil research methods with GPR and IR technologies. They found that some GPR reflection results correspond to changes of water content in soil and gravel content in soil profile, but they could not prove correlation between spatial changes of soil properties and radar reflection. Through IR, it is able to observe vegetation coverage and growth, but it can not reflect relationship with properties of reclaimed soil. Some scholars identify and monitor quality of reclaimed soil with the aid of Landsat TM data set, and make evaluation on the basis of changes of vegetation index. Researches have shown that remote sensing data can provide timely and rapid information for evaluation of reclaimed soil quality in a large area. Philip D. Schroeder believed that the key to improve productivity of reclaimed soil lies in effective mixing of mining materials and maintenance and increase of soil humus[1]. C. A. Seybold *et al* considered that properties of surface soil can be improved through optimum management practice and quality basically can be controlled; the quality of profile soil is generally low, mainly limited by bad soil structure, low ef-

fective water content, and constant increase in bulk density of lower layer soil[2]. Shukla, M. K. *et al*, through analyzing main composition of physical and chemical properties of 0 to 10 cm soil in Ohio State, pointed out that the bulk density of soil is the largest distinguishing factor, while water-stable aggregate is the leading factor measuring soil attribute or dynamic quality indicators. Change law of other soil indicators is soil bulk density > field moisture capacity > clay content[3]. Manfred Kaufmanna *et al* studied mechanical stability of reclaimed soil where the cultivation was restored within three years, reached the conclusion that the soil bulk density and penetration resistance constantly increase, while the coarse porosity decreases obviously, but all are kept within the range suitable for crop growth. The pre-stress has obvious increase in both surface soil and subsoil, while the compression index of surface soil is significantly greater than that of subsoil and keeps steady in the entire observation period[4]. Manfred Kaufmanna *et al* evaluated the productive potential of reclaimed soil based on mechanical resistance and permeability with the aid of fuzzy logic expert system[5]. Likhatsevich A. P. *et al* determined the productivity of reclaimed agricultural land through analyzing soil fertility features and suitable fertilizers in several consecutive years[6]. Wilson *et al* took physical and chemical properties of soil, climatic factors and landscape features as indicators for evaluating crop productive potential of reclaimed soil[7]. Robert E. Dunke *et al* established the soil-based productivity model by regressive and multivariate methods, as the means to determine whether the reclaimed soil in mining area has the potential of standard crop productivity. They proposed taking simulation of soil variability combined with yield requirement as diagnostic tool of mining area[8].

2 Progress in domestic researches on evaluation of quality of cultivated land consolidated from coal mining subsided land

2.1 New technologies for evaluating quality of cultivated land consolidated from coal mining subsided land In recent years, domestic scholars have carried out a series of researches on technologies (such as Ground Penetrating Radar (GPR), remote sensing image, and electromagnetic induction conductivity meter) for evaluating quality of cultivated land consolidated from coal mining. Compared with traditional site sampling method, these technologies can detect major factors influencing quality of cultivated land, to greatly reduce destruction of land and adverse effect on environment; information acquisition will be more convenient and swift, and reflect regional distribution of acquired information to a certain extent. At present, China has realized effective measurement of soil layer structure, soil coverage thickness and water content in coal mining subsided land through GPR; made quantitative research on soil saline pollution combining mathematic model; measured apparent electric conductivity of soil coverage in land consolidated area using EMEM38 electromagnetic induction conductivity meter, and explored the correlation between apparent conductivity and coverage thickness; realized calculation analysis and level division of vegetation coverage through establishing model with the aid of ERDAS IMAGINE remote sensing image processing system.

2.2 Evaluation of soil quality of land consolidated from coal mining subsided land During consolidation of coal mining subsided land, soil mass changes greatly due to huge disturbance. Besides, different process and consolidation years have different influence on soil quality. As the basis of cultivated land quality, soil quality becomes a hot issue among domestic scholars. Different from foreign scholars taking physical features of soil as research points, domestic ones conduct research from soil fertility condition, environmental quality and comprehensive quality of soil.

2.2.1 Evaluation of soil fertility: As the basis of land productivity, soil fertility provides nutrients, water, air and heat for plant growth, is the comprehensive reflection of physical, chemical and biological features of soil. Extensive researches of domestic scholars indicate that at the early stage of consolidation, soil fertility is low. With increase of consolidation years, physical and chemical features of soil gradually become normal, and soil fertility is also constantly improved. Zhang Leina *et al* analyzed the influence of land consolidation years on nutrient content and physical property of soil, and believed that after four years of consolidation, soil fertility can reach or exceed the medium level, and crop yield can constantly increase[9]. Gu Zhiquan put forward major features of soil fertility after consolidation: soil body configuration is bad, not favorable for growth of root system; content of soil nutrient is low, and spatial variation is large, basic fertility is lower than normal farmland[10]. Wei Tingting *et al* selected organic matter, quick-acting P, quick-acting K and pH value to evaluate soil fertility of three typical areas in Huai'nan mining area using entropy-based model. They pointed out that in the course of agricultural production, it should stress the plowing and fertilizer fostering on consolidated soil surface[11]. Li Wei introduced main composition analysis method and fuzzy mathematical method into evaluation of fertility of consolidated soil, reached the conclusion that vertical distribution of fertility quality takes on declining trend, the overall level gets close to 90% of normal farmland, suitable cultivation and fertilization fostering are favorable for improvement in fertility quality[12].

2.2.2 Evaluation of soil environmental quality: The soil which is consolidated from coal mining subsided land is often polluted by heavy metal, consequently threatening security of crops and water resources. At present, most domestic scholars analyze heavy metal content and change law in soil by field sampling, leaching test and planting test, apply ecological risk index method, Nemerow index method, and grey clustering method into evaluation of soil environmental quality of coal mining subsided land. These researches show that coal ash and gangue filling generally have the problem of pollution, and it is urgent to take proper measures to control or improve.

Now, coal ash powder is widely applied in filling soil in coal mining subsided land in Jiangsu, Anhui and Hebei provinces.

Relevant researches indicate that soil filled by coal ash powder gets polluted. The pollution of surface soil is worsened with increase of consolidation years, but content of elements has no obvious change in depth; heavy metals in coal ash powder seldom move with water and will remain in soil for a long time; high pH value of coal ash powder can passivate pollution of heavy metal, and heavy metal content in stalks and leaves and fruit of crops conforms to national food sanitary standard; it proves that coal ash powder filling and covering 30 cm surface soil can bring the heavy metal content in crop stalks and leaves to normal level, so it is an economic and reliable soil reconstruction method.

The overall pollution level of soil filled by gangue is also very high. Average value of many heavy metals, such as Cd, Hg, Cr and Zn, is higher than soil background value, and there is no obvious law of each element in vertical distribution of soil body. Cd has the largest contribution to the overall pollution level and this can be restored through planting proper plant that has restoration function. Moreover, in high phreatic water level area, leaching and migration of fluorine in gangue may exert influence on water quality.

In deeper subsided area, surface runoff inputs a lot of heavy metals. Therefore, at the bottom of subsided soil, there will be greater content of heavy metal, especially Cr. However, with increase of consolidation years, the pollution degree of soil is declining.

2.2.3 Evaluation of soil comprehensive quality: Domestic scholars evaluate overall quality of soil in coal mining subsided land mainly from soil fertility and environmental quality. The evaluation time point includes static change (certain time point after consolidation) and dynamic change (increase with consolidation years). On the basis of Neill's soil productivity coefficient model, Hu Zhenqi established fuzzy PI model to quantitatively evaluate reclaimed soil productivity, considering relative importance of soil property, and difference in function of each soil layer to soil productivity[13]. Gu Hehe *et al* evaluated soil productivity of typical slurry pump reclaimed land, bulldozer reclaimed land and normal farmland in Pingdingshan coal mining area with the aid of fuzzy soil productivity index (PI) model through indicators such as soil bulk density, water content, permeation rate, organic matter, total nitrogen, quick-acting P and quick-acting K. Evaluation results show that the productivity of slurry pump reclaimed soil is lower than normal farmland parcel due to high water content and slightly little nutrient, but higher than the soil of bulldozer reclaimed land[14]. Chen Longqian and Deng Kazhong evaluated the quality of reclaimed soil from productivity and environmental quality, and compared with normal farmland, to reflect actual effect of reclaimed land[15]. Bian Zhengfu and Zhang Guoliang contended that the fuzzy PI model does not consider the correlation between time and space change of reclaimed soil productivity and factors, and put forward a modified productivity index (MPI) model[16]. Ren Junjie realized the three – dimensional visual expression of spatial distribution of reclaimed soil property and productivity index through establishing digital soil property model[17]. Qian Guimei evaluated reclamation effect from soil fertility, ecological environmental quality and soil health quality, and divided it into four levels[18]. Ma Wenming established a comprehensive model for evaluating reclaimed soil quality of slurry pump reclaimed land through field survey and analysis from four factors, including physical composition of soil, nutrient content, pH value and noxious substance. He reached the conclusion that the soil quality of slurry pump reclaimed land is only 75.7% of normal farmland, and put forward proper measures for technology and soil improvement[19].

Wang Yunping *et al*[20] and Sun Taisen *et al*[21] analyzed physical property, nutrient and heavy metal content of soil reclaimed by mixed pushing and peeling methods. They reached the conclusion that the soil fertility obtained from peeling method is obviously better than the mixed pushing method. Furthermore, with increase of reclamation years, the soil fertility gets constantly improved, but the heavy metal content, especially in surface layer, takes on a rising trend, which will pollute both the soil and underground water. Liu Xueran *et al* found that different filling material, operating machinery, cropping system, and fertilizer application will exert influence on the quality of reclaimed soil[22]. Li Wei *et al* proved that the nutrient content of reclaimed soil increases with increase of reclamation years, and decreases with increase of soil depth. To return to normal soil nutrient level, it needs further ameliorative measures[23].

2.3 Researches on evaluation of quality of cultivated land consolidated from coal mining subsided land There are limited domestic researches on evaluation of quality of cultivated land consolidated from coal mining subsided land. Bian Zhengfu *et al* believed that environment, soil and input are three major factors influencing productivity of reclaimed land, and derived the dynamic equation of productivity change and entropy exchange model (EEM)[24]. Zhang Xianzhong *et al* built cultivated land and garden land quality evaluation indicator system according to natural condition and capital farmland construction, and studied changes in quality level of agricultural land by multiple factor evaluation method and standard parcel method[25]. Zhang Danfeng proposed idea of comprehensive quality evaluation on the basis of environmental quality of soil reaching the standard[26]. Lu Huanzhe *et al* evaluated the quality of reclaimed land by grey correlation method from soil productivity, soil environment and farmland production construction, and put forward that the soil productivity is leading factor influencing quality of cultivated land[27]. Li Jingjing *et al* analyzed farmers' recognition of cultivated land quality, farmers' input and output, and changes in annual yield of reclaimed cultivated land, and reached the conclusion that farmers' living condition and their behavior influence the quality of reclaimed cultivated land[28]. Zhang Gengjie *et al*, on the basis of grading of agricultural land, introduced a new idea of grading reclaimed land in mining area, and built the evaluation indicator system for land grading[29]. Li Yuejie *et al* evaluated quality of reclaimed land in mining area by grading method, and predicted level of supplementary cultivated land to be reclaimed according to set scene[30].

3 Existing problems and future prospects

Currently, there are following existing problems in the research on evaluation of quality of cultivated land consolidated from coal mining subsided land. (1) Domestic researches focus on soil quality. Foreign scholars pay close attention to physical and chemical properties of soil, while domestic ones study from soil fertility and environmental quality. Both neglect influence of land use and economic condition on the quality of cultivated land. (2) Domestic researches are mainly carried out from soil fertility, environmental quality, farmland infrastructure. There are two types: most scholars select indexes according to the characteristics of cultivated land consolidated from coal mining subsided land, such as soil bulk density and heavy metal content of soil and so on; while a few studies are completely in accordance with the agricultural land grading index of local. Comparatively speaking, the former type fails to satisfy vertical and horizontal comparison of quality of cultivated land due to inconsistency of evaluation indicator system, while the latter fails to objectively reflect actual quality of land due to neglect of special features of consolidated land. (3) At present, overall level of cultivated land consolidated from coal mining subsided area is generally low. There are problems of poor soil fertility, heavy metal pollution, and lack of systematic research on relevant improving technologies.

Systematic research on this evaluation can provide reference for monitoring quality of cultivated land in coal mining area and for land requisition – compensation balance, which is also helpful for constantly improving land consolidation scheme in mining area, as well as provide basic material for constantly improving land consolidation scheme and improving quality of cultivated land in mining area. According to requirements of the *Notice on Improving Protection Level and Comprehensive Strengthening Construction and Management of Cultivated Land* (No. 108 in 2012) issued by Ministry of Land and Resources, all areas should carry out evaluation in accordance with *Procedures for Grading Quality of Agricultural Land*. Besides, the *Standard for Construction of High Level Capital Farmland* also clearly specifies that the quality of consolidated cultivated land should be evaluated according to *Procedures for Grading Quality of Agricultural Land*. However, there are significant differences between consolidated and natural cultivated land, and these differences can not be reflected from grading indicators of agricultural land. The existing studies of evaluation indexes and methods vary enormously. Therefore, it is a key research point to establish scientific and feasible evaluation system, which can reflect characteristics of quality of consolidated cultivated land, and which can realize comparison of quality change in the dynamic course of "undisturbed – subsided – consolidated" cultivated land in coal mining areas. In addition, technologies for improving quality of cultivated land consolidated from coal mining subsided land is also an issue worthy of discussion.

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3.3 Continuing to tap the quality enhancement potential of arable land The good quality of arable land is the basis of improvement in the level of food production. The arable land output in Chengdu City still has potential for considerable mining space, and the substance of improving effective irrigation area and the area of low-yielding field is to improve the quality of arable land. So, we need to rely on scientific and technological means to increase agricultural inputs and continue to improve the quality of arable land and arable land output in Chengdu City.

Firstly, we should increase input into breeding, cultivation, soil improvement, biological control of pests and diseases; abandon the old way of relying on chemical fertilizer to increase yield; secondly, we should strengthen the comprehensive land management, renovate the irrigation and drainage system, build the farm track, strengthen water conservancy construction, develop efficient facility agriculture, to do a good job in rural infrastructure building; for the low-yielding fields, it is necessary to improve the soil, increase soil fertility, fully use the rich organic matter resources in the Chengdu Plain, and guide farmers to reasonably use organic fertilizers[12].

3.4 Consistently implementing the guideline and policy of "Combination of Use and Maintenance" Chengdu City should implement the guideline and policy of "Combination of Use and Maintenance", focus on the point of view of building large-scale farming, and improve the development of ecological agriculture[13-14], in order to eliminate the hazards of unsafe state from the source.

The focus is to promote the application of organic fertilizer, reduce the application of pesticides and chemical fertilizer, use scientific means to choose the best fertilizing and spraying time, improve the efficiency in the use of chemical fertilizers, and pesticides, reduce drug residues; establish clear system of agricultural environmental protection, comprehensively control the pollution problems in arable land, improve, repair and purify the soil with poor conditions.

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