Advances in Application of Models in Soil Quality Evaluation

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Abstract Soil quality is a comprehensive reflection of soil properties. Since the soil quality concept was put forward in the 1970s, the quality of different type soils in different regions have been evaluated through a variety of evaluation methods, but it still lacks universal soil quantity evaluation models and methods. In this paper, the applications and prospects of grey relevancy comprehensive evaluation model, attribute hierarchical model, fuzzy comprehensive evaluation model, matter-element model, RAGA-based PPC/PPE model and GIS model in soil quality evaluation are reviewed.

Key words Soil quality, Evaluation model, Application

1 Introduction

Soil quality, introduced by Warkentin and Fletcher in 1977[1], refers to the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation[2]. Soil quality is a complex of physicochemical and biological properties of soil and essential process forming these properties. It emphasizes protection of crops' productivity and environment, food security, and plant and animal health. For the above reasons, soil quality becomes a research focus of modern soil science[3]. Nevertheless, with rapid development of global economy and population, soil quality deteriorates sharply and brings about many ecological, environmental and global problems. Therefore, it is required to evaluate current situation of soil quality, so as to provide precondition and reference for restoration and administration of degraded soil.

Early evaluation of soil quality is mainly qualitative description oriented, which means soil quality is evaluated based on observation of outer appearance and other superficial phenomena of soil. For instance, soil is graded through observation of soil animals, organic matters color, root system and remnants, surface soil compactibility, soil tilth, erosion condition, water holding capacity, penetrability, crops growth conditions *etc.* There is detailed description of characteristics for each grade of each item and qualitative situation of soil is thus derived based on grading evaluation of these items. However, evaluation results differ from person to person and lack comparability. Therefore, it is necessary to develop quantitative evaluation methods based on the qualitative approach, so as to enable quantitative comparison of soil quality. With the development of computer technology, introduction of mathematical models and information technology (GIS) has made evaluation of soil quality more quantitative, sensible, reliable and informative. I herein review the applications of grey relevancy comprehensive evaluation model, attribute hierarchical model, fuzzy comprehensive evaluation model, matter-element model, RAGA-based PPC/PPE model and GIS model for soil quality evaluation, so as to provide basis for proper selection of soil quality evaluation methods.

2 Application of models in soil quality evaluation

With the application of information technology in soil quality evaluation, quantitative mathematical evaluation methods, including osculating value method, grey relevancy evaluation method, grading nearness degree method, fuzzy evaluation method, cluster analysis method and geo-statistics method, as well as various appropriate mathematical models are applied and developed gradually. Introduction of models has made soil quality evaluation more logical and systematical. Different models are introduced into evaluation of soil quality upon different requirements of evaluation and have become a research focus currently.

2.1 Grey relevancy comprehensive evaluation model

Relevancy analysis method in the grey system is a factor analy-

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sis approach, which analyzes the relevancy degree of multiple factors in the system. The grey relevancy comprehensive evaluation model is designed on the principle of grey relevancy analysis. It classifies soil quality by calculating the degree of similarity between a sample and the " ideal sample" that has optimal values for each index, *i. e.* the grey relevancy comprehensive evaluation value[4]. This method is characterized by simple operation, less calculation and reliable theoretical basis, and is suitable for comprehensive evaluation with multiple indices.

Hu Yueming *et al.*[4], by taking the experimental region of agricultural modernization for lateritic red soil in Dongguan, Guangdong Province for example, have evaluated the soil quality of this region through application of GIS technology and combination of hierarchical analysis model and grey relevancy comprehensive evaluation model, and obtained rating of soil quality of each evaluated unit. The grey relevancy comprehensive evaluation model requires no evaluation criteria for each evaluated factor rather than the original quantitative values of each factor; therefore, its results are more objective, more scientific and more valuable for making soil resources utilization decision. Feng Lin *et al.*[5], based on investigation of the attributes of different types of sandy soil in the experimental region in Aer Town, Zhangwu County, have made comprehensive evaluation of soil quality and obtained reasonable evaluation results, by building a comprehensive evaluation index system with combination of the indices which reflect the soil attributes and the time indices which reflect the growing period of vegetation, as well as developing software of grey relevancy evaluation model. Lu Huanzhe *et al.*[6] applied this model to evaluate the reclaimed land quality and thought that procedures of this method is simple and easy to operate.

This model doesn't use evaluation criteria for each factor, so its evaluation results are more objective. In addition to this, its revaluation results also give quality order of each unit, while it is also possible to classify soil quality grade of each unit according to the degree of relevancy. Therefore, the grey relevancy comprehensive evaluation model not only has more scientific approach, but also gives more results, and it is of great reference value for soil quality evaluation.

2.2 Attribute hierarchical model Attribute hierarchical model (AHM) is put forward by Professor Cheng Qiansheng in 1997 based on attribute measurement[7]. It is a new model of method without structure decision. It requires neither consistency check nor characteristic vector. This model is more understandable, and its calculation is easier. It also takes full consideration of weight differences among each evaluation index; therefore, its evaluation results are more objective and accurate. There are 3 levels in the structure of this model. The top level is the goal level, *i. e.* comprehensive evaluation of soil quality. The bottom level is the evaluation object (sample) level. The middle level is the criteria level, including each index of soil quality evaluation. The middle level can be further divided into several levels if required. In this hierarchical structure, each goal, criteria and evaluation object is called an element. Each element (except for elements on the bottom level) as a criteria dominates over related elements of the next level[8].

Zhao Qing *et al.* applied the attribute identification model and the hierarchical analysis model to perform comprehensive analysis on soil fertility of Changling County, Jilin Province. Their results are consistent with the evaluation results of fuzzy comprehensive evaluation model. Hong Mianmian *et al.*[10] applied this model to perform comprehensive evaluation of 8 samples and 6 heavy metal pollution indices in the agricultural environment. It is found that results of this method are slight different from fuzzy comprehensive evaluation method but consistent with those of osculating value method. Therefore this model is highly feasible for soil quality evaluation.

Attribute hierarchical model has been successfully applied in air quality evaluation, urban environment evaluation and water resources evaluation, but is seldom used in soil quality evaluation. This method has large amount of work to do, though simple and easy to operate, so it is suitable for data of small sample size (*i. e.* number of samples is less than 10)[11]. There are many data in the soil evaluation system in practice; therefore it is necessary to use it together with other computer technologies. In addition, this model is more suitable for quality evaluation with evaluation criteria.

2.3 Fuzzy comprehensive evaluation model Since fuzzy mathematics is put forward by Zadeh in 1965, fuzzy comprehensive evaluation model has been fully developed and widely applied in decision making and evaluation[12-14]. Fuzzy comprehensive evaluation model is a multi-factors evaluation method. It quantifies fuzzy indices of the evaluated soil through construction of fuzzy subsets of grades, integrates each index based on fuzzy transform principle, uses degree of membership to describe fuzzy classification boundary of soil quality, and the degree of membership of each evaluation grade is then corrected with weight of each evaluation factor. In this way, the degree of membership of the evaluated sample with respect to evaluation grade is obtained[15]. This model is considered as a classic theory. The grade concept of soil quality is unclean and influenced by various factors, but fuzzy comprehensive evaluation is most effective in solving problems of fuzzy boundary and can control the error of evaluation results. In the evaluation process it is characterized by clear hierarchy, definite physical significance and higher resolution, compared with other evaluation models[16-17].

In recent years, the fuzzy comprehensive evaluation model has greatly developed from simple application to expanded application. Wu Wei[18] *et al.* applied the fuzzy comprehensive evaluation model to evaluate the nutrient condition of dark purple paddy soil. It turns out that this model is more reliable and accurate in factor quantification. The final evaluation values of each evaluated unit not only reflect relative grades among each unit, but also can directly reflect absolute grades of each unit. Wang Jianguo[19] *et al.*, based on the fact that there exists fuzziness in soil quality evaluation, have put forward a thought of building soil quality single-factor evaluation and comprehensive evaluation models using fuzzy mathematics methods, carried out empirical analysis, and obtained satisfactory results. In order to improve resolution of evaluation results and enable them to more comprehensively and factually reflect the actual situation of soil quality, Dou Lei[16] *et al*. applied a fuzzy comprehensive evaluation model of double weight factors to evaluate the heavy metal pollution situation of soil. This model overcomes the defect of easy error judgment of other models such as hierarchical analysis model. Duan Yonghui[20] improved the accuracy of evaluation results by building a fuzzy comprehensive weighted average model to reduce information loss. With development of this model, computer programming technology is also applied in it. Zhang Xue *et al*.[21] applied VB programming and MAPINFO software in it. They took Dongting Lake region of Hu'nan Province for experiment, carried out analysis and processing of various data by using weighted average fuzzy mathematical model and VB programming, obtained degree of membership value of each factor, then performed weighted stacking of multiple factors, and finally got a soil quality grade diagram using MAPINFO. Comparison of different fuzzy comprehensive evaluation methods have gradually drawn more focus, such as comparison between the single-factor decision and the weighted average fuzzy mathematical model[22].

Fuzzy comprehensive evaluation model has been widely applied in various aspects of soil environment, such as evaluation of soil nutrient situation[23], soil suitability evaluation, land degradation evaluation[24], soil pollution situation (such as heavy metal pollution) evaluation and classification, reflection of degree of influence of each pollution factor on soil quality, and division and quantification of pollution degree *etc*[26]. Results of various researches have proven the scientificity, feasibility and reliability of this model in soil quality evaluation. It has great application potential, and is possible to be used in soil classification, land evaluation and planning, soil process simulation, and other sustainable development evaluation of ecology, environment, water resources and so on. The application of this model involves weight matrix susceptible to subjective factors, leading to subjective tendency of classification and evaluation results. However, this can be avoided by combined application with other methods. Therefore, it is widely use.

2.4 Matter-element model Professor Cai Wen, a Chinese scholar, first put forward the matter-element analysis theory. This theory studies rules and methods of contradiction problems, focuses on facilitating transformation of things and solving incompatible problems, and is suitable for evaluation of multiple factors. Matter-element analysis model is applied in soil quality evaluation in such a way of constructing matter elements with soil quality grades, evaluation indices and its characteristic values, building classic domain, joint domain, weight set and relevancy function of the model, calculating weight coefficient of each evaluation index using hierarchical analysis method, and realizing comprehensive evaluation and order sorting of various soil samples based on the calculated comprehensive relevancy degree. Pan Feng[27] *et al*., on the basis of hierarchical analysis method, applied this model to perform soil quality comprehensive evaluation for of 21 types of samples in Songhua River region and obtained satisfactory effect. They thought its application should be promoted.

Shi Jianjun[28] *et al*. built a matter-element model for soil unit suitability evaluation with the extension theory and method. With this matter-element model, it is possible to calculate the suitability grade and best usage of a soil unit based on initial values of each attribute of this soil unit. In this way it provides basic data and decision reference for comprehensive utilization of land resources.

Matter-element analysis method is easy to use. Its evaluation results is sensible and reliable, and its relevancy degree can truly reflect the real situation of each soil index. For evaluation problem with multiple indices and quality grades, computers can be used for calculation to overcome the shortcoming of tedious complex calculation.

2.5 Projection pursuit model of real coding based accelerating genetic algorithm Projection Pursuit Model (PP Model) is a method that can be used in dimension reduction analysis of high-dimensional data. It is first put forward and tested by Kruskal in the early 1970s[30]. Then Friedman and Tukey (1974)[31] combined overall scatter degree and local agglomeration degree to form new indices and perform cluster analysis and classification analysis. Also they formally put forward the concept of PP Model. In 2002, Fu Qiang[32] *et al*. combined Real coding based Accelerating Genetic Algorithm (RAGA) and Projection Pursuit Classification Model (PPC Model). He optimized the projection direction parameters using RAGA and transformed high-dimensional data to low-dimensional space. In this way he integrated multiple indices of each sample into a comprehensive index, performed ordering and identification using projection values and thus built a projection pursuit Model for soil quality comprehensive evaluation to realize evaluation of soil samples. He also used soil quality data of Sanjiang plain to verify the model, and the results indicate it is feasible. He also used PPC model to build a Projection Pursuit Grade Evaluation Model (PPE Model) for standard soil samples and grouped those with similar function values into a grade. The results basically matched the fact[33]. PPE model is based on PPC model with just simple modification and the same principle. PPE model is also characterized by high suitability and commonality. Given an evaluation criteria list and values of each index of the evaluated object, it is possible to perform evaluation without the need to consider the nature of the evaluation problem. Therefore, it is widely used for evaluation[34].

With combination of RAGA and PP Model, it is possible to optimize many parameters of PP Model using RAGA and thus greatly simplifies PP modeling process. Meanwhile, PP Model avoid interfere of human given weight, so its results are more objective and reliable. It is worthy of further promotion for use in soil quality evaluation.

3 Prospect

Geological Information System (GIS) is a new technology for study of space information generated with the development of computer technology in the 1960s. It is a computer system for comprehensive management and analysis of space data of the objective world, including corresponding space data and attribute data. It has strong space analysis ability, region integration ability and dynamic forecasting ability. Soil quality evaluation is one of the mature field where GIS is first applied. With introduction and application of GIS technology, the regions to be studied are divided into certain amount of meshes. Each of these meshes is considered as an individual basic evaluation unit and evaluated one by one. In this way it reduces influence of human factors, better reflects on large scale the fuzziness of soil quality evaluation and dynamic forecasting of soil quality. In addition, its final results can be output as a series of delicate subject pictures[35].

With continuous development of information technology, application of GIS is gradually expanded. It develops especially quick in the field of quality evaluation for soil and other natural resources with combination with other analysis method or application models, such as combined application with GIS remote sensing technology, Visal Basic software, hierarchical analysis method, fuzzy mathematical method, degree of membership model, geostatistics method, Nemoro formula, weighted index and method, dynamic clustering model, Pressure-status – Response (PSR) model *etc*[36–40]. Meanwhile, many researchers applied various GIS supported methods and models in soil evaluation and obtained satisfactory results, thus provided decision making basis for rational utilization of soil resources or for inspection of soil quality situation and rules[41–45]. Integration of GIS system with various mathematical models would be an important trend in further development of soil quality evaluation.

4 Discussion

There are many models and methods for soil quality evaluation, but few of them can be widely promoted due to their limitation of accuracy and range of application for quality evaluation. Soil environment is a large open ecological system. Data used for evaluation for it is obtained from limited regions, so the information provided by models for systematical description of the environment quality condition is incomplete and unspecific due to limitation of time and space. Therefore, in the process of soil quality evaluation, we should select suitable models and methods according to the index characteristics and goals of the evaluation, integrate several models and methods to make up short points with other's merits mutually and verify each other so as to obtain scientific, reliable and sensible evaluation results where possible.

Soil quality evaluation study has just started for not a long time. It involves each filed of agrology and relates to various aspects of land utilization, agricultural and forestry industries planting measures and management *etc*. In the process of soil quality evaluation, there exist many problems waiting for immediate solutions, including quantitatively monitoring variety of each evaluation index over time and space, clearly identifying factors that influence or reflect soil functions as well as relationship among them, improving model accuracy and methods for evaluation. Soil quality evaluation requires to develop a series of indices, grading criteria, threshold values for soil quality, quantities and dynamic evaluation methods and models so as to accurately monitor and pre-alarm the dynamic changes of soil quality, including its key processes. It is expected to find a relatively accurate, easy to use comprehensive quantitative evaluation system model widely suitable for different regions, utilization types, soil types and scales with macro scales in particular, with the help of hi-tech software such as GIS in future research.

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