Application of Matter-element Model in Soil Nutrient Evaluation of Ecological Fragile Region

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Abstract: On the basis of the soil environment investigation in Da′an City, Jilin Province, China, 40 soil samples from main land use types were obtained and tested by standard method. Soil organic matter (SOM), total N (TN), total P (TP), total K (TK), available N (AN), available P (AP) and available K (AK) were chosen as the evaluation factors. A regional soil nutrient evaluation model was developed based on the matter-element model. The results show that the soil samples with nutrient grade Ⅱ–Ⅴ respectively account for 10%, 30%, 32.5% and 27.5%, and those with grade Ⅳ and Ⅴ account for 60% in all samples. The relationship between soil nutrients and land types indicates that the nutrients of farmland are relatively good, with 41.7% of soil samples with the nutrient grade Ⅳ and Ⅴ. The nutrients of saline-alkali land and sandy land are the worst, with 100% of soil samples with the nutrient grade Ⅳ and Ⅴ. And the ratios of soil samples grade Ⅳ and Ⅴ in grassland and wasteland are respectively 62.5 % and 54.55%. Generally speaking, the soil nutrients status in Da′an City is poor, 60% of soil samples are in poor and extremely poor conditions, indicating that the soil has been severely eroded. Being a relatively superior evaluation method with more accurate results and spatial distribution consistency, matter-element analysis is more suitable for regional soil nutrient evaluation than previous models.

Keywords: soil nutrient evaluation; matter-element model; extension engineering theory; ecological fragile region

1 Introduction

Soil nutrient is an important material foundation of soil fertility (Shui and Wang, 2008). Under the influences of natural and man-made factors, different types of soils contain different nutrients and the soils have obvious characteristics of spatial and temporal distribution (He and Ning, 2004). It is of theoretical and practical significance to make the soil nutrients evaluation and study soil nutrients and their distribution characteristics for improving utilization rates of land resources and soil nutrients (Su et al., 2006).

The most traditional methods of soil nutrients evaluation always compartmentalize the levels of soil fertility indicators and determine their relative weights artificially. The evaluation criteria are not unified, and thus the methods are not easy to be generalized and applied. As the numerical evaluation method was proposed and further applied, soil nutrients evaluation was gradually changing to being integrative and quantitative. In recent years, the methods such as analytic hierarchy process (AHP), principal component analysis, grey correlation method, fuzzy comprehensive evaluation, linear regression and artificial neural network method have been often used for soil nutrients evaluation (He and Kang, 1994; Wu et al., 2000; DeBusk et al., 2001; 2007; Lu et al., 2002; Gao et al., 2003; Victor et al., 2004; Yang and Wang, 2005; Wang et al., 2007; An et al., 2007). All those methods have their own advantages and disadvantages. The principal component analysis, linear regression and grey correlation method can reduce the evaluation factors and have high veracity, but their workloads are more. The workload of AHP is less, but it needs more expertises. In addition, many of them ignore the influence of various factors on the collectivity of soil nutrients.

The evaluation criteria of the methods mentioned above are quantitative ones with obvious bounds and the dividing lines of soil nutrients grades are blurred, which will omit some useful information or even lead to reach-

ing wrong conclusions. Soil nutrient is a multi-indicator system, and a specific indicator can only describe one side of the system (He and Kang, 1994). The critical concept in extension set casts off binary restriction of "either this or that" in classical mathematical theory, which indicates the transition state in the natural world. Matter-element model has been widely used in the comprehensive evaluation of the environmental quality and product quality classification as well as agricultural resources evaluation (Wu et al., 2006; Tang and Li et al., 2005; Xiang and Xiang, 1999). But there are few reports on soil nutrients evaluation using matter-element model. It is the first time to carry out soil nutrients evaluation by matter-element method at home and abroad. The matter-element model developed from the extension theory, and it fully considered each indicator of soil nutrients. Each indicator is chosen as the internal structure of soil nutrients and all indicators are the entity of quality and quantity of soil nutrients. However, the internal structure of each indicator is changing and decomposing, so it is not static. By introducing the negative concept to establish the correlation degree between the various indicators and the entity，this method can integrate all information to ensure the information integrity. All the above can reveal the relationship between the internal structure of the soil nutrients and the various indicators, and determine the basic situation of the regional soil nutrients better. For this reason, this paper tries to use matter-element model to carry soil nutrients evaluation in the ecological fragile region, which has great significance for the land resources restoration and land productivity improvement.

2 Study Area

Da'an City, in the northwest of Jilin Province of China, is located in 44°57'00"–45°45'51"N and 123°08'45"–124°21'56"E, with a total area of 4879km² (Fig. 1). At present, the total population of the city is $420×10^3$, of which the agricultural population is $300×10^3$. It belongs to the temperate monsoon climate. The average annual sunshine time is 3012.8 hours, and the average annual temperature and the average annual accumulated temperature are respectively 4.3℃ and 2921.3℃. The average annual precipitation is 413.7mm and the annual average evaporation is 1696.3mm. There are 150 frost-free days and 26.5 strong wind days every year on av-

erage. Because Da'an City is located in the hinterland of the Songnen Plain, the terrain there is flat and open, with an elevation of 120–160m. Flat land, low-lying land, platform and dunes are respectively 26.5%, 48.8%, 15.0% and 9.7% of the total area. The main rivers in the region are the Nenjiang River, the Tao′er River and the Huolin River. The soil types include chernozem soil, light chernozem soil, aeolian sandy soil, meadow soil, alluvial soil, swamp soil and saline-alkali soil. The fertility of the soil is relatively poor. Soil organic matter contents are lower, which are commonly about 1%. The soils generally lack nitrogen and phosphorus seriously, and some parts lack potassium.
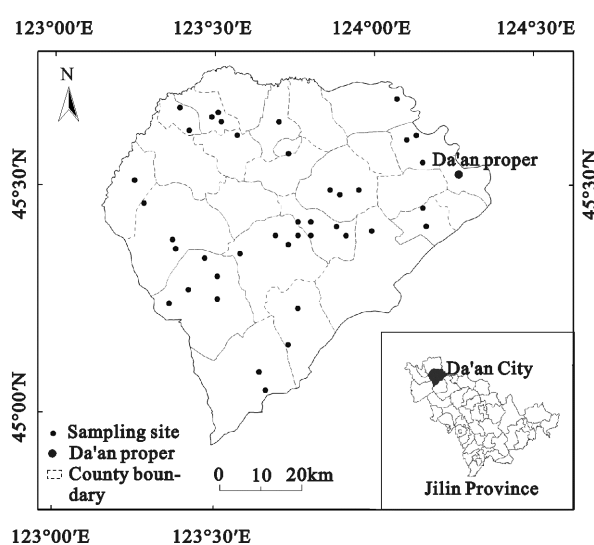

Fig. 1 Location of study area and sampling sites

In the past half a century, under the dry climate in the global warming background, coupled with irrational exploitation and utilization of natural resources by human beings, the ecological environment of Da′an City deteriorated rapidly. The deterioration mainly behaved as drought and water shortage, salinization, desertification, grassland degradation and lake shrink. Various types of land use have been seriously damaged, which hamper the development of agriculture and animal husbandry (Tang and Wang, 2008). Up to now, Da'an City remains the national needy county. Therefore, it is of great significance to carry out the land resources survey and do the soil nutrients evaluation for the land resources restoration and land productivity improvement.

3 Materials and Methods

3.1 Soil sample collection and test method

In July 2007, the authors took the soil environment investigation in 25 towns in Da'an City and did the S-shaped sampling in the typical land. Forty mixed soil samples (0–30cm) were collected (Fig. 1), including paddy field，dry land, grassland, saline-alkali land, desert and so on.

The testing items included soil organic matter (SOM), total N (TN), total P (TP), total K (TK), available N (AN), available P (AP) and available K (AK). SOM was measured with the $K_2Cr_2O_6$ heating method; TN, with Semi-micro Kjeldahl method; TP, with H_2SO_4-$HClO_4$-Mo-Sb-Vc-colormetry; TK, with H_2SO_4-HF-HNO_3-Flame photometer; AN, with diffusion and alkaline hydrolysis; AP, with alkaline hydrolysis $NaHCO_3$-extraction-Mo-Sb-Vc-colormetry; and AK, with ammonium acetate extracts Flame photometer (Li et al., 2003; Li, 1989; Tang et al., 2003; Yuan et al., 2006). Normal method was used in the all tests. The accuracy and reproducibility are better, with less than 5% of relative deviation. The sample recovery rates of the test methods ranged from 94% to 105%. All those can meet the analysis requirements.

3.2 Integrated matter-element model

Chinese mathematician CAI Wen put forward the matter-element analysis theory to solve the incompatible problems for first time in the 1980s. The theoretical system had been established from the initial matter-element analysis to extension engineering theory (Cai, 1994; Cai et al., 2000). The basic content of matter-element analysis is as follows. Firstly, define the class intervals of each evaluation indicator. Then, calculate the single index correlation degree to determine the soil nutrients state by single indicator. Finally, the comprehensive soil nutrients grades of all indicators are gained by model integration. Therefore, the evaluation results of matter-element analysis are more reasonable and accurate than the ones of other methods.

3.2.1 Matter-element definition

A given thing is named M, whose characteristic c is valued V. The orderly ternary group $R=(M, c, V)$ is the basic element for describing things, which is named matter-element for short. One thing has a number of characteristics. If thing M has n characteristics $c_1, c_2, \ldots, c_n$ and the corresponding values are $v_1, v_2, \ldots, v_n$, the matter-element can be expressed as:

$$R = (M, c, V) = \begin{vmatrix} M, & c_1, & v_1 \\ & c_2, & v_2 \\ & \vdots & \vdots \\ & c_n, & v_n \end{vmatrix} \quad (1)$$

3.2.2 Classical domain establishment

If the thing has m levels with $N_{01}, N_{02}, \ldots$ and N_{0m}, the matter-element (R_{0j}) is

$$R_{0j} = (N_{0j}, c_i, X_{0ji}) = \begin{vmatrix} N_{0j}, & c_1, & X_{0j1} \\ & c_2, & X_{0j2} \\ & \vdots & \vdots \\ & c_n, & X_{0jn} \end{vmatrix} = \begin{vmatrix} N_{0j}, & c_1, & <a_{0j1}, & b_{0j1}> \\ & c_2, & <a_{0j2}, & b_{0j2}> \\ & \vdots & \vdots \\ & c_n, & <a_{0jn}, & b_{0jn}> \end{vmatrix} \quad (2)$$

where N_{0j} is the jth elavation level (j=1, 2, …, m); c_i is the ith evaluation indicator; X_{0ji} is the jth-level value range of c_i, that is the classical domain. The range of X_{0ji} is interval $<a_{0ji}, b_{0ji}>$, which can be recorded as $X_{0ji} = <a_{0ji}, b_{0ji}>$, i=1, 2, …, n.

3.2.3 Section domain establishment

According to the classical domain, the section domain (R_p) is

$$R_p = (P, c_i, X_{pi}) = \begin{vmatrix} P, & c_1, & X_{p1} \\ & c_2, & X_{p2} \\ & \vdots & \vdots \\ & c_n, & X_{pn} \end{vmatrix} = \begin{vmatrix} P, & c_1, & <a_{p1}, & b_{p1}> \\ & c_2, & <a_{p2}, & b_{p2}> \\ & \vdots & \vdots \\ & c_n, & <a_{pn}, & b_{pn}> \end{vmatrix} \quad (3)$$

where P is the whole evaluation levels, and the X_{pi} is the value range of c_i. All that is the P section domain, which can be recorded as $X_{pi} = <a_{pi}, b_{pi}>$, i=1, 2, …, n. Obviously, X_{0ji} belongs to X_{pi}.

3.2.4 Establishment of matter-element of evaluation object

The matter-element of evaluation object can be expressed as:

$$R_0 = (P_0, c_i, V_i) = \begin{vmatrix} P_0, & c_1, & v_1 \\ & c_2, & v_2 \\ & \vdots & \vdots \\ & c_n, & v_n \end{vmatrix} \quad (4)$$

The equation is called evaluation matter-element of P_0. V_i is the specific value of indictor c_i of the evaluation object.

3.2.5 Correlation degree between evaluation index and evaluation level

The correlation degree ($K_j(v_i)$) between evaluation index

and evaluation level is calculated based the classical domain and section domain.

$$K_j(v_i) = \begin{cases} -\dfrac{\rho(v_i, X_{0ji})}{|X_{0ji}|}, (v_i \in X_{0ji}) \\ \\ \dfrac{\rho(v_i, X_{0ji})}{\rho(v_i, X_{pi}) - \rho(v_i, X_{0ji})}, (v_i \notin X_{0ji}) \end{cases} \quad (5)$$

where $\rho(v_i, X_{0ji}) = |v_i - 0.5(a_{0ji} + b_{0ji})| - 0.5(b_{0ji} - a_{0ji})$; $|X_{0ji}| = |a_{0ji} - b_{0ji}|$, $(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m)$, $\rho(v_i, X_{pi}) = |v_i - 0.5(a_{pi} + b_{pi})| - 0.5(b_{pi} - a_{pi})$. $\rho(v_i, X_{0ji})$, $\rho(v_i, X_{pi})$ are respectively the distances between v_i and classical domain X_{0ji} and section domain X_{pi}. In fact, correlation degree $K_j(v_i)$ expresses the ownership between index and the level j, which equals to the subjection degree in fuzzy sets of Fuzzy Math. The value range of subjection degree in fuzzy math is the closed interval [0, 1], but the one of correlation degree is the entire range of real axis. If $K_j(v_i) = \max K_j(v_i)$, $j \in (1, 2, \ldots, m)$, the evaluation indicator v_i belongs to level j.

3.2.6 Correlation degree between evaluation object and its corresponding grade

The correlation degree ($K_j(P_0)$) of evaluation object and its corresponding grade can be calculated by

$$K_j(P_0) = \sum_{i=1}^{n} a_i K_j(v_i) \quad (6)$$

where a_i is the weight of the corresponding index c_i, and $\sum a_i = 1$. $K_j(P_0)$ is the combined value of the correlation degree when considering the importance of indexes, and it expresses the correlation degree between evaluation object P_0 and its corresponding grade j. If $K_j(P_0) = \max K_j(P_0)$, $j \in (1, 2, \ldots, m)$, P_0 belongs to level j.

The value of the correlation degree in the real axis expresses the subjection degree between the evaluated object and a certain grade. The logic value of the correlation degree in matter-element model is in the real axis $(-\infty, +\infty)$ rather than the closed interval [0, 1] in Fuzzy Math. Thus, it has more abundant connotation than that in Fuzzy Math and it can reveal more variant information. If $K_j(P_0) > 0$, the evaluation object is in line with the requirements of a certain grade standard, and the degree of the accordance increases with its value. If $-1 < K_j(P_0) < 0$, the evaluation object is not in line with the requirements of a certain grade standard, but it has the condition to transform into that grade, and its greater value makes it easier to transform. If $K_j(P_0) < -1$, the evaluation object is not in line with the requirements of a certain grade standard, but it does not have the condition to transform into that grade, and its smaller value indicates the bigger gap between evaluated object and evaluation criteria.

4 Results and Analyses

4.1 Selection of elevation factors and their weights

According to the soil quality characteristics in Da'an City and the economic supporting capacity of the program, the paper chose the SOM, TN, TP, TK, AN, AP and AK as evaluation indexes and used AHP method to give their weights (Tang and Zhao et al., 2005). AHP uses quantitative way to express and handle the people's subjective judgment and realizes the integration of qualitative analysis and quantitative analysis. It solves the weight ascertainment problem in the assessment model. Firstly, judging matrix is built by 1–9 scale. And then, the maximal characteristic root of judging matrix and its corresponding characteristic vector are calculated. The vector component turns to be the weight of every factor in originally tiers. According to the research results in 2005, the evaluation factors' weights were gained by adopting square root law supported with Excel software (Table 1).

Table 1 Weight of soil nutrient evaluation factors in Da'an City

SOM	TN	TP	TK	AN	AP	AK
0.401	0.182	0.096	0.065	0.106	0.09	0.06

Source: Tang and Zhao et al., 2005

4.2 Establishment of classical domain, section domain and matter-element of evaluation object

Using the extension set concept (Cai et al., 2000), the gradual classification relation set {Richness→Moderate richness→Proper amount→Poorness→More poorness} is extended from qualitative description to quantitative description, so soil nutrients with different grades can be identified. If P= {Richness→Moderate richness→Proper amount→Poorness→More poorness}, N_{01}=Richness, N_{02}=Moderate richness, N_{03}=Proper amount, N_{04}=Poorness, N_{05}=More poorness, then N_{01}, N_{02}, N_{03}, N_{04}, $N_{05} \in P$. For any $p \in P$, the correlation degrees of p to N_{01}, N_{02}, N_{03}, N_{04}, and N_{05} are judged. In this paper, the soil nutrients classification criteria from the second national soil survey of China (Table 2) was adopted, and the soil nutrients evaluation classical domain R_{01}, R_{02}, R_{03}, R_{04}, R_{05} and section domain R_P were established.

Table 2 Classification standard of soil nutrients

Grade	SOM (%)	TN (%)	TP (%)	TK (%)	AN (mg/kg)	AP (mg/kg)	AK (mg/kg)
I Richness	4.0	0.200	0.20	3.0	150	40	200
II Moderate richness	3.0	0.150	0.15	2.0	120	20	150
III Proper amount	2.0	0.100	0.10	1.5	90	10	100
IV Poorness	1.0	0.075	0.07	1.0	60	4	50
V More poorness	0.6	0.040	0.05	0.5	30	3	30

Source: Cui, 2007

The specific values of various factors c_i about evaluated object were used to determine the matter-element of evaluated object. The values were the test data of 40 soil samples. Taking sampling site S_1 of Dawa Village in Da'an City as an example, the test data are SOM 1.4%, TN 0.08%, TP 0.034%, TK 2.265%, AN 43.45mg/kg, AP 10 mg/kg and AK 111.25mg/kg, according to which the matter-element of sampling site 1 (S_1) was determined.

Classical domain:

$$R_{01} = \begin{vmatrix} N_{01}, & c_1, & <3, & 4> \\ & c_2, & <0.15, & 0.2> \\ & c_3, & <0.15, & 0.2> \\ & c_4, & <2, & 3> \\ & c_5, & <120, & 150> \\ & c_6, & <20, & 40> \\ & c_7, & <150, & 200> \end{vmatrix}$$

$$R_{02} = \begin{vmatrix} N_{02}, & c_1, & <2, & 3> \\ & c_2, & <0.1, & 0.15> \\ & c_3, & <0.1, & 0.15> \\ & c_4, & <1.5, & 2> \\ & c_5, & <90, & 120> \\ & c_6, & <10, & 20> \\ & c_7, & <100, & 150> \end{vmatrix}$$

$$R_{03} = \begin{vmatrix} N_{03}, & c_1, & <1, & 2> \\ & c_2, & <0.075, & 0.1> \\ & c_3, & <0.07, & 0.1> \\ & c_4, & <1, & 1.5> \\ & c_5, & <60, & 90> \\ & c_6, & <4, & 10> \\ & c_7, & <50, & 100> \end{vmatrix}$$

$$R_{04} = \begin{vmatrix} N_{04}, & c_1, & <0.6, & 1> \\ & c_2, & <0.04, & 0.075> \\ & c_3, & <0.05, & 0.07> \\ & c_4, & <0.5, & 1> \\ & c_5, & <30, & 60> \\ & c_6, & <3, & 4> \\ & c_7, & <30, & 50> \end{vmatrix}$$

$$R_{05} = \begin{vmatrix} N_{05}, & c_1, & <0, & 0.6> \\ & c_2, & <0, & 0.04> \\ & c_3, & <0, & 0.05> \\ & c_4, & <0, & 0.5> \\ & c_5, & <0, & 30> \\ & c_6, & <0, & 3> \\ & c_7, & <0, & 30> \end{vmatrix}$$

Section domain:

$$R_p = \begin{vmatrix} N_p, & c_1, & <0, & 4> \\ & c_2, & <0, & 0.2> \\ & c_3, & <0, & 0.2> \\ & c_4, & <0, & 3> \\ & c_5, & <0, & 150> \\ & c_6, & <0, & 40> \\ & c_7, & <0, & 200> \end{vmatrix}$$

Matter-element of evaluation object:

$$R_{S_1} = \begin{vmatrix} P_{S_1}, & c_1, & 1.400 \\ & c_2, & 0.080 \\ & c_3, & 0.034 \\ & c_4, & 2.265 \\ & c_5, & 43.45 \\ & c_6, & 10.00 \\ & c_7, & 111.25 \end{vmatrix}$$

4.3 Evaluation results analyses

The evaluation results can be obtained by inputting the specific data of evaluation object matter-element to equations (5) and (6). Taking single index c_1 (SOM) as an example, v_1 (1.4) is input to Equation (5). The corresponding correlation degree between this indicator and each grade is as follows: $K_1(v_1)=-0.533$, $K_2(v_1)=-0.300$, $K_3(v_1)=0.400$, $K_4(v_1)=-0.222$ and $K_5(v_1)=-0.364$. Based on the judging criteria, $K_3(v_1)=\max K_j(v_1), j \in (1, 2, 3, 4, 5)$. So the soil nutrients grade of this indicator is N_{03}, which is proper amount grade (III). The corresponding correlation degree between S_1's other indicators and each

level and the soil nutrients grades can be obtained by using the same method. On this basis, the correlation degree between various indicators and each grade and the corresponding weight (Table 1) were input to Equation (6), and the integrated correlation degrees between all indicators and each grade were calculated by the weighted sum. The results are as follows: $K_1(P_{S_1})=-0.487$, $K_2(P_{S_1})=-0.279$,

$K_3(P_{S_1})=0.045$, $K_4(P_{S_1})=-0.219$, $K_5(P_{S_1})=-0.312$. Based on the judging criteria, $K_3(P_{S_1})=$Max $K_j(P_{S_1})$, $j \in$ (1, 2, 3, 4, 5). So the soil nutrients grade of S_1 is N_{03}, which is proper amount grade.

All the calculation results of S_1 were shown in Table 3. The relevant calculation results of samples S_2–S_{40} can be obtained in the same steps.

Table 3 Soil nutrients correlation degree $K_j(v_1)$ and $K_j(P_{S_1})$ of S_1 (dry land) in Da'an City

Indicator	Correlation degree	N_{01}	N_{02}	N_{03}	N_{04}	N_{05}	Nutrient grade
SOM	$K_j(v_1)$	−0.533	−0.300	0.400	−0.222	−0.364	III
TN	$K_j(v_2)$	−0.467	−0.200	0.020	−0.059	−0.333	III
TP	$K_j(v_3)$	−0.773	−0.660	−0.514	−0.320	0.320	V
TK	$K_j(v_4)$	0.265	−0.265	−0.510	−0.633	−0.706	I
AN	$K_j(v_5)$	−0.638	−0.517	−0.276	0.103	−0.236	IV
AP	$K_j(v_6)$	−0.500	0.001	−0.001	−0.375	−0.412	II
AK	$K_j(v_7)$	−0.304	0.225	−0.113	−0.408	−0.478	II
Sampling site	$K_j(P_{S_1})$	−0.487	-0.279	0.045	−0.219	−0.312	III

The soil nutrients integrated correlation degrees of 40 sampling sites in Da'an City were calculated by the above method and the soil nutrients grade were judged according to the integrated correlation degree (Table 4). Then the correlation analysis on land use types and soil nutrients grades was carried on, the results are shown in Table 5.

After making data statistical calculation in Table 4 and Table 5, some characteristics of using matter-element model on soil nutrient evaluation can be seen: Firstly, the samples in the major land type are generally well-distributed. Percentages of the samples in farmland (including dry land and paddy field), grassland, wilderness and degraded land (saline-alkali land, desert) were respectively 32.5%, 20%, 27.5% and 20%. Therefore, the sampling was representative. Secondly, there is no soil sample with nutrient grade Ⅰ in the study area. The soil samples with nutrient grade Ⅱ−Ⅴ respectively account for 10%, 30%, 32.5% and 27.5%; and those with grade Ⅳ and Ⅴ account for 60% in all samples. Thirdly, seen from relationship between the soil nutrients and the land types, the nutrients level of farmland are relatively good, with 41.7% of soil samples with the nutrient grade Ⅳ and Ⅴ. The nutrients of saline-alkali land and sand land are the worst, with 100% of soil samples with the nutrient grade Ⅳ and Ⅴ. And soil samples with nutrient grade Ⅳ and Ⅴ in grassland and wilderness were respectively 62.5 % and 54.55%. Generally speaking, the soil nutrients status in Da'an City is poor, 60% of soil samples are in poor and extremely poor conditions, indicating that the soil has

been severely eroded.

4.4 Evaluation result verification

The authors once studied the environment evolution and analyzed the causes of land desertification in the Songnen Plain. According to the research, the main desertification type there is land salinization. At the same time, they drew the desertification classification map of Da′an City in the hinterland of the Songnen Plain (Lin and Tang, 2005). And they also drew the interpretation map of TM images of land-use types in Da′an City in 2006. So the accuracy of soil test data and soil nutrients evaluation can be verified by the different types of remote sensing data. First of all, the authors spaced each sampling site according to geographic coordinates by using Erdas Imagine8.6 to form the spatial distribution map of soil samples in Da'an City. Then, the spatial distribution map of sampling sites, the desertification classification map and the interpretation map of TM images of land-use types were spatially overlaid by "Overlay" order of Arc Toolbox module in ArcGIS (Fig. 2). From Fig. 2, it can be seen that there is high correlation degree between the soil nutrients grade, land use types and desertification degree. Soil sampling sites with moderate and proper nutrients are mainly distributed in relatively good quality farmland and grassland or in slight desertified land. The soil sampling sites with poor and poorer nutrients are mainly distributed in the saline-alkali land, desert and poor quality farmland and grassland or in the moderate and severe desertified land.

Table 4 Soil nutrients of 40 sampling sites in Da′an City

Correlation degree	N_{01}	N_{02}	N_{03}	N_{04}	N_{05}	Grade judgment	Nutrients grade	Land type	Correlation degree	N_{01}	N_{02}	N_{03}	N_{04}	N_{05}	Grade judgment	Nutrients grade	Land type
$K_j(P_{S_1})$	−0.487	−0.279	0.045	−0.219	−0.312	N_{03}	III	DL	$K_j(P_{S_{21}})$	−0.322	0.251	−0.201	−0.416	−0.458	N_{02}	II	G
$K_j(P_{S_2})$	−0.43	−0.153	0.135	−0.262	−0.357	N_{03}	III	DL	$K_j(P_{S_{22}})$	−0.572	−0.616	−0.505	−0.259	0.095	N_{05}	V	G
$K_j(P_{S_3})$	−0.52	−0.45	−0.233	0.189	−0.239	N_{04}	IV	G	$K_j(P_{S_{23}})$	−0.471	−0.526	−0.31	0.031	−0.326	N_{04}	IV	G
$K_j(P_{S_4})$	−0.412	−0.092	0.037	−0.179	−0.376	N_{03}	III	DL	$K_j(P_{S_{24}})$	−0.615	−0.416	−0.288	−0.072	0.133	N_{05}	V	S
$K_j(P_{S_5})$	−0.45	−0.218	−0.134	0.014	−0.339	N_{04}	IV	G	$K_j(P_{S_{25}})$	−0.518	−0.325	0.018	−0.167	−0.281	N_{03}	III	W
$K_j(P_{S_6})$	−0.375	−0.246	−0.13	0.082	−0.348	N_{04}	IV	S	$K_j(P_{S_{26}})$	−0.669	−0.596	−0.585	−0.431	0.144	N_{05}	V	G
$K_j(P_{S_7})$	−0.713	−0.636	−0.487	−0.363	0.154	N_{05}	V	S	$K_j(P_{S_{27}})$	−0.251	−0.224	0.156	−0.348	−0.456	N_{03}	III	W
$K_j(P_{S_8})$	−0.55	−0.414	−0.232	−0.281	0.174	N_{05}	V	DL	$K_j(P_{S_{28}})$	−0.322	−0.251	0.201	−0.416	−0.458	N_{03}	III	DL
$K_j(P_{S_9})$	−0.497	−0.338	−0.172	0.029	−0.292	N_{04}	V	S	$K_j(P_{S_{29}})$	−0.432	−0.254	0.1	−0.277	−0.351	N_{03}	III	W
$K_j(P_{S_{10}})$	−0.491	−0.313	−0.269	0.034	−0.245	N_{04}	V	DL	$K_j(P_{S_{30}})$	−0.594	−0.563	−0.318	0.068	−0.187	N_{04}	IV	W
$K_j(P_{S_{11}})$	−0.593	−0.455	−0.084	0.069	−0.228	N_{04}	V	DL	$K_j(P_{S_{31}})$	−0.646	−0.548	−0.429	−0.215	0.062	N_{05}	V	W
$K_j(P_{S_{12}})$	−0.377	0.095	−0.167	−0.307	−0.316	N_{02}	II	P	$K_j(P_{S_{32}})$	−0.696	−0.647	−0.683	−0.587	0.142	N_{05}	V	W
$K_j(P_{S_{13}})$	−0.715	−0.621	−0.429	−0.166	0.013	N_{05}	V	W	$K_j(P_{S_{33}})$	−0.542	−0.4	−0.116	0.048	−0.275	N_{04}	IV	W
$K_j(P_{S_{14}})$	−0.434	−0.368	0.125	−0.615	−0.634	N_{03}	III	DL	$K_j(P_{S_{34}})$	−0.683	−0.557	−0.384	−0.211	0.113	N_{05}	V	S
$K_j(P_{S_{15}})$	−0.396	−0.117	0.089	−0.322	−0.309	N_{03}	III	G	$K_j(P_{S_{35}})$	−0.28	0.028	−0.128	−0.366	−0.434	N_{02}	II	G
$K_j(P_{S_{16}})$	−0.644	−0.547	−0.298	0.005	−0.154	N_{04}	IV	DL	$K_j(P_{S_{36}})$	−0.352	−0.249	0.18	−0.433	−0.386	N_{03}	III	W
$K_j(P_{S_{17}})$	−0.492	−0.275	0.046	−0.238	−0.293	N_{03}	III	DL	$K_j(P_{S_{37}})$	−0.431	0.1	−0.489	−0.603	−0.578	N_{02}	II	DL
$K_j(P_{S_{18}})$	−0.593	−0.455	−0.084	0.069	−0.228	N_{04}	IV	S	$K_j(P_{S_{38}})$	−0.646	−0.548	−0.429	−0.215	0.062	N_{05}	V	DL
$K_j(P_{S_{19}})$	−0.537	−0.311	0.097	−0.172	−0.263	N_{03}	III	W	$K_j(P_{S_{39}})$	−0.519	−0.352	−0.191	0.041	−0.307	N_{04}	IV	D
$K_j(P_{S_{20}})$	−0.714	−0.575	−0.404	−0.195	0.013	N_{05}	V	W	$K_j(P_{S_{40}})$	−0.509	−0.33	−0.191	−0.116	−0.28	N_{04}	IV	D

Notes: P: Paddy field; DL: Dry land; G: Grassland; W: Wilderness; S: Saline-alkali land; D: Desert

Table 5 Correlations between soil nutrient grade of 40 sampling sites and land-use types in Da'an City

Nutrients grade	Dry land		Paddy field		Grassland		Wilderness		Saline-alkali land		Desert		Total	
	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%	Amount	%
I	–	–	–	–	–	–	–	–	–	–	–	–	–	
II	1	8.3	1	100	2	25.0	–	–	–	–	–	–	4	10.0
III	6	50.0			1	12.5	5	45.5	–	–	–	–	12	30.0
IV	3	25.0			3	37.5	3	27.3	2	33.3	2	100	13	32.5
V	2	16.7			2	25.0	3	27.3	4	66.7	–	–	11	27.5
Total	12	100	1	100	8	100	11	100	6	100	2	100	40	100
%	30		2.5		20		27.5		15		5		100	

The outstanding merits of the matter-element applied in soil nutrient evaluation are as follows: it can judge each nutrient grade of soil samples objectively, but also determine the level of each nutrient factor. For example, rich nutrient soil has rich SOM, TN and AN, but TK is not obvious. The P may be rich in poor and very poor soil. In order to find the the main factors influencing soil nutrients, the authors did factor analysis. The soil samples were analyzed by Factor Analysis module of SPSS14.0 (Su et al., 2002). From the component matrix (Table 6), there are two public factors influencing soil nutrients in Da'an City. The first factor is mainly decided by SOM, TN and AN, and the second factor is mainly decided by TK and AK, which indicates that the main factors influencing soil nutrients are SOM, TN and AN.

The results showed that the soil nutrient evaluation classification had higher accuracy in the numerical and spatial distribution.
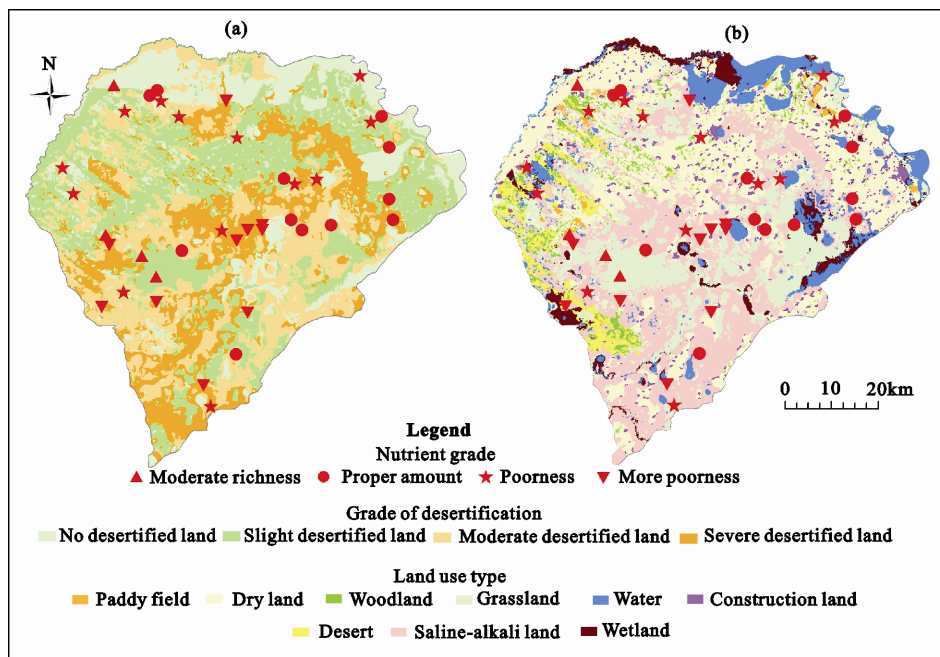
Fig. 2 Overlay map of nutrient grade of soil sampling site and desertification
classification (a) and the land use map (b) in Da'an City

Table 6 Component matrix

Component	SOM	TN	TP	TK	AN	AP	AK
1	0.903	0.862	0.533	−0.433	0.776	−0.531	−0.337
2	0.116	0.002	−0.194	0.740	−0.103	0.417	0.841

5 Conclusions

The matter-element analysis based on the extension math can summarize the practical issues as compatible or incompatible issues. The correlation degree of matter-element develops the logic value from the closed interval [0, 1] in fuzzy math to the real axis $(-\infty, +\infty)$. It can integrate all information without losing factors to ensure the integrity of the information by introducing the negative concept to establish the correlation degree. The study scope was expanded and more different information can be revealed. The correlation degree in extension set expressed by mathematical equation can make the research issue quantified.

It is the first time to carry out soil nutrient evaluation using matter-element method at home and abroad. This method can compartmentalize the soil nutrients type reasonably and effectively and thus evaluate soil nutrients level objectively and scientifically. Therefore, it has broad application prospects. However, it still has imperfectness in theory and practical application. For example,

the available correlation function options are less. Up to now, only the basic forms of function in actual number of domain, the second-order correlation function and n-order correlation function are established. Therefore, the matter-element model has yet to be further developed and improved.

Compared with other method, the matter-element analysis method in soil nutrient evaluation has outstanding advantages. It can not only make the overall assessment on the soil nutrient accurately, but also evaluate each factor separately. Thus it can find out the contribution rate of soil nutrients factors to the overall in order to make the fertilization and soil improvement pertinently.

Based on the evaluation results, the soil nutrient status in Da′an City is poor, and there is no soil with nutrient grade Ⅰ in the study area. The soil samples with nutrient grade Ⅱ–Ⅴ respectively account for 10%, 30%, 32.5% and 27.5%; and those with grade Ⅳ and Ⅴ account for 60% in all samples, indicating that the soil has been severely eroded. Seen from relationship

between the soil nutrients and the land types, the nutrients of farmland are relatively good, the nutrients of saline-alkali land and sandy land are the worst. The soil with nutrient grade Ⅳ and Ⅴ lacks SOM, TN and AN. None soil lacks TK and AK. If more soil nutrients data were obtained, the evaluation results would be of greater value. Being a relatively superior evaluation method with more accurate results and spatial distribution consistency, matter-element analysis is more suitable for regional soil nutrient evaluation than previous models.

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