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Effect of Reclamation Time and Land Use on Soil Properties in Changjiang River Estuary, China

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Abstract: The objective of this study is to analyze soil physical and chemical properties, soil comprehensive functions and impact factors after different years of reclamation. Based on the survey data taken from 216 soil sampling points in the Fengxian Reclamation Area of the Changjiang (Yangtze) River Estuary, China in April 2009 and remotely sensed TM data in 2006, while by virtue of multivariate analysis of variance (MANOVA), geo-statistical analysis (GA), principal component analysis (PCA) and canonical correspondence analysis (CCA), it was concluded that: 1) With the increase in reclamation time, soil moisture, soil salinity, soil electric conductivity and soil particle size tended to decline, yet soil organic matter tended to increase. Soil available phosphorous tended to increase in the early reclamation period, yet it tended to decline after about 49 years of reclamation. Soil nitrate nitrogen, soil ammonia nitrogen and pH changed slightly in different reclamation years. Soil physical and chemical properties reached a steady state after about 30 years of reclamation. 2) According to the results of PCA analysis, the weighted value (0.97 in total) that represents soil nutrient factors (soil nitrate nitrogen, soil organic matter, soil available phosphorous, soil ammonia nitrogen, pH and soil particle size) were higher than the weighted value (0.48 in total) of soil limiting factors (soil salinity, soil electric conductivity and soil moisture). The higher the F value is, the better the soil quality is. 3) Different land use types play different roles in the soil function maturity process, with farmlands providing the best contribution. 4) Soil physical and chemical properties in the reclamation area were mainly influenced by reclamation time, and then by land use types. The correlation (0.1905) of the composite index of soil function (F) with reclamation time was greater than that with land use types (–0.1161).

Keywords: soil properties; land use types; reclamation time; soil function; Changjiang River Estuary

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1 Introduction

The earth′s surface system has been undergoing changes under the combined influence from natural forces and social economic factors for centuries (Forman, 1995; Zonneveld, 1995; Fu *et al*., 2006). With increasing demand for land, ′land reclamation from the sea′ has become an important way to meet this demand. The environmental impact of reclamation has drawn much attention. The Netherlands is well-known for land reclamation from the sea. It pays more attention to the variation in soil trace elements after reclamation (De Vos *et al*., 2002), loss of chemical elements (Spijker *et al*., 2005), heavy metals accumulation (Hesterberg *et al*., 2006) and habitat simulation after reclamation (Puijenbroek *et al*., 2004). In other countries, studies on reclamation focus

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more on soil toxicity (O'Rourke *et al*., 2001), environmental transition (Hatvany, 2003) and habitat simulation of wild plants (Hammersmark *et al*., 2005) after reclamation. Principal component analysis clearly identified the chemical and biochemical soil properties mostly affected by the reclamation (Vito *et al*., 2009) on the left bank of the Guadalquivir River in the Marisma de Lebrija.

In China, numerous studies concerning reclamation and its environmental impact have also been performed, and these were generally focused on four aspects: 1) Biological effects of reclamation (Tang and Lu, 2002; Yuan *et al*., 2002; Shen *et al*., 2006). It was found that the number of plant species increase along with time after construction of a seawall; and after 30 years plant species in community increase greatly and the soil pH is basically close to neutral (Shen *et al*., 2006). 2) The aquatic environment (Han *et al*., 2001). Early study showed that the differences of land-use types in a reclamation area would cause different pollution types and pollution levels (Chen and Xu, 2004). 3) Socio-economic-water benefits (Lin, 2003; Li *et al*., 2004; Li *et al*., 2007). Ecosystem service diversity falls while the total value of ecosystem service increases. Industrial wastewater, mariculture wastewater inside and outside the reclamation area, farmland tillage backwater and domestic sewage are the major factors causing water quality pollution inside and outside the reclamation area and tidal flat sediment pollution (Lin, 2003). 4) Soil environment. Li and Shi (2005) and Wu *et al*. (2008) conducted the spatial distribution evaluation study of soil elements and soil quality in the reclamation area. Yang and Yao (2009) studied the spatial variability of soil nutrient characteristics in the reclamation area, and found that the spatial variability of soil nutrient characteristics is influenced by both structural factors and stochastic factors. Soil compaction and soil physical and chemical characteristics were affected by land reclamation in different layers (Hu *et al*., 2009).

There are currently many studies concerning the environmental impacts of reclamation, yet few are focused on the relationships between reclamation time, land use types and soil environment. To avoid blind reclamation or inappropriate land use after reclamation, understanding the environmental evolution of reclaimed land will provide a scientific basis for policymaking on coastal reclamation and polder management.

In this study, using reclamation time and land use types as the impact factors of soil functions, nine indices of soil physical-chemical properties were identified as indicators of soil functionality. This study focused on a part of the Changjiang (Yangtze) River estuary and analyzed the spatial and temporal differentiation of soil function by virtue of multivariate analysis of variance (MANOVA), canonical correspondence analysis (CCA), principal component analysis (PCA) and geo-statistical analysis (GA), and finally established the correlativity between time, land-use types and soil properties. Our hypotheses are: 1) soil properties change systematically with time after reclamation; 2) different land-use types would result in the spatial differentiation of soil physical-chemical properties; 3) the comprehensive functions of soil in the reclamation area are influenced by the reclaimed time and land-use types. This study is designed to determine the degree of influence from the above factors and provide scientific basis for the management of the reclamation area. The results will also contribute to the understanding of the relationship between ′pattern and process′ in landscape ecology (Li and Mander, 2009).

2 Materials and Methods

2.1 Study area

The study area is located in the Fengxian reclamation area of the Changjiang River estuary on the northern coast of the Hangzhou Bay. The coastline is 20 km long from west to east (Fig. 1), while the width of the study area is 11.7 km from south to north. The area has a north subtropical monsoon climate with four distinct seasons: short spring and autumn, and long summer and winter. Summer is hot and humid, with frequent thunderstorms and rainfall, and winter is cold. Strong sunshine, high temperature and high precipitation fall in the same season of a year, which is beneficial for multiple cropping in agriculture. From 1853 to 1900, the silty tidal flat was reclaimed after the first dyke was built. After the founding of the People′s Republic of China in 1949, more reclamation was conducted by building dams, including Renmin dam of 1960 (Jin, 2007), Tuanjie dam of 1974 (Jin, 2007), Jinhui dam of 1979 (Jin, 2007), and Blue Sea and Gold Sand dam of 2006 (Jin, 2007) (Fig. 1), which created a reclamation area with different time series. The study area is divided into five reclamation zones (Fig. 1) based on the years of reclamation, which were recorded from the *Water Conservancy Annuals of Fengxian District, Shanghai* (Jin, 2007). Several years after reclamation, land-use types and soil functions often become significantly varied. This was an ideal place for the investigation of the relationship between landscape patterns and processes.

2.2 Data collection

2.2.1 Land use data

Landsat TM data with a solusion of 30 m obtained from Changjiang River estuary in 2006 was processed with Erdas 9.2 and GIS 9.2 to obtain the categorial landscape map in the study area. The land-use types (Chen and Zhou, 2007) and their descriptions are listed in Table 1. The classification accuracy of land-use types are 92% or higher for open water, aquaculture pond, mud flat and greenhouse land; over 85% for dry land, irrigated land, forest land, grassland and orchard land, and over 90% for built-up land and unutilized land.

2.2.2 Soil data

Totally 216 sampling points (Fig. 1) were selected in the five reclamation zones in April 2009. According to the extent of the study area (20 km × 6 km), random uniform grid method was used for sampling. Each grid had a size of 0.5 km × 0.5 km, and GPS was used for positioning. The distribution of sampling points in each reclamation zone is shown in Fig. 1. Soil was sampled from 0–20 cm depth and mixed. Relevant information (such as soil type, vegetation, and land use) was also carefully recorded. All samples were air dried in laboratory under normal temperature condition. Nine indices of soil physical-chemical properties were selected to represent soil quality: soil particle size, soil organic matter, available phosphorous, nitrate nitrogen, ammonia nitrogen, soil moisture, soil salinity, electric conductivity, and pH.

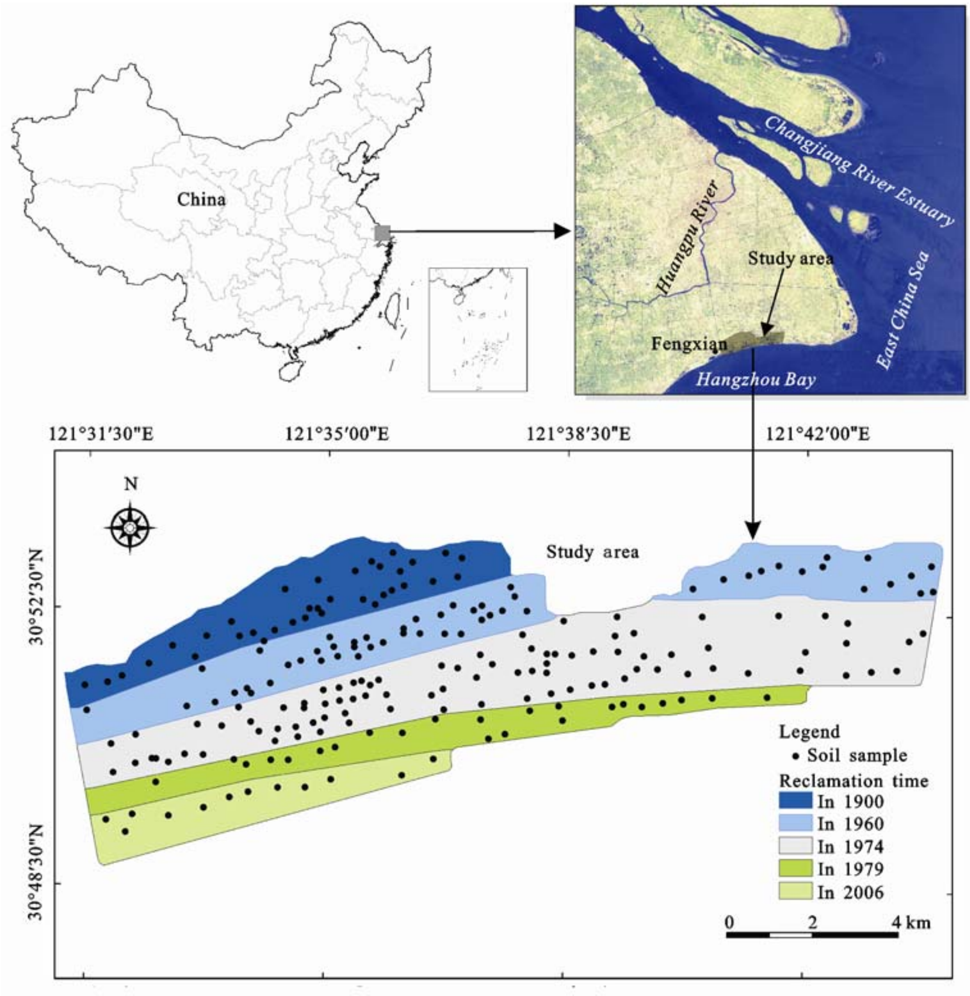


Fig. 1 Location of study area with soil sampling points

Table 1 Land use types and their descriptions of study area in 2006

Land use type	Description	Classification accuracy
Grassland	Reed marsh tidal flat, pasture and grassland in parks	0.90
Mudflat	Bare land being pumped seawater out of reclamation area	0.92
Aquaculture pond	Pond land for feeding aquatic animals such as fish, shrimps and crabs	0.85
Open water	Rivers, lakes, field streams and non-cultured waterbody	0.92
Unutilized land	Unutilized tillage and abandoned farmland	0.90
Forest land	Forest land along fields, land for forest park and sparse woodland	0.90
Orchard	Land for perennial crops, such as fruits and flowers	0.90
Dry land	Land for planting corn, cotton, winter wheat, *etc*.	0.85
Irrigated land	Non-greenhouse land for planting various seasonal vegetables	0.85
Greenhouse land	Land that adopts greenhouse farming all the year round for cultivating vegetables and cash crops	0.90
Built-up land	Reclamation dam, residential land, building land for industrial and mining enterprises	0.90

Soil moisture, salinity, electric conductivity and pH were assessed directly during the field survey with a salt-water apparatus (SDI-12 / RS485, made in Australia) and soil pH meter. Soil particle size was obtained with the laboratory′s laser particle size analyzer (LS 100Q made in America). Organic matter, available phosphorous, nitrate nitrogen and ammonia nitrogen were measured in laboratory with Soil Nutrient-Temperature-Humidity Instruments (TFW-VI made in China) (Li *et al*., 2010).

2.3 Methods

2.3.1 Variance analysis of soil physical-chemical properties

Multivariate analysis of variance (MANOVA) can indicate the significance levels of soil property differences at different reclamation times. According to the statistics of relationships between different descriptive models and dependent variables, four MANOVA tests (Wilks′ Lambda, Lawley-Hotelling, Pillai′s Trace and Roy′s Largest Root) are often selected, while the difference levels between groups are represented by F-statistics. An independence test and multivariate normality test (Matheron, 1963) were conducted on soil properties data in the study area. BOX statistics were employed to check whether or not the covariance matrix is equal. If the data conforms to the normality and has statistical significance, MANOVA analysis can be performed.

2.3.2 Comprehensive evaluation of soil functions

Principal Component Analysis (PCA) is a method to regroup the numerous correlation indices into a new set of independent composite indices to replace the original ones (Qishlaqi *et al*., 2009). In this paper, the original nine soil properties indices were linearly combined into a new composite index. In this method, the first selected linear combination (F1) variance is used to represent the set; that is, the larger variance (F1) is, the more information is contained in F1. As that, a new set of composite indices is created as linear combinations of the original nine indices. The principal components can also be used to conduct a comprehensive evaluation of soil properties, and obtain the comprehensive evaluation index F based on nine soil properties data, which can better reflect the comprehensive levels of the soil system and provide a vital approach for dimension reduction and the evaluation of soil functions.

2.3.3 Analysis of spatial characteristics of soil properties and function

Geo-statistical analysis (GA) is based on the theory of self-organizing variance (Matheron, 1963). In our study, the semi-variance estimation of soil properties data and PCA analysis results is obtained using GS 5.0+. Its equation is as follows (Matheron, 1963):

$$r(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} \left[Z(x_i + h) - Z(x_i) \right]^2 \qquad (1)$$

where h refers to the spatial distance between sampling points; $n(h)$ refers to the number of sample point pairs, when the separation distance is h; $Z(x_i)$ and $Z(x_i + h)$ refer to the sample values of variable x at spatial points i and $i + h$ respectively. The geo-statistical analysis places emphasis on revealing the anisotropy of the spatial distribution or spatial autocorrelation characteristics of the isotropy of soil properties. In terms of the difference of data characteristics of geographical factors, the spatial semi-variable function usually adopts different data models (spherical, exponential, Gaussian, linear, or pure nugget effect). The model is generally described through the following four parameters: Nugget (the y-intercept of the model, C_0), Sill (the model asymptote, $C_0 + C$), Range (the distance over which spatial dependence is apparent, A_0), and Nugget to sill ratio (NSR = $C_0 / (C_0 + C)$) (Kashem and Singh, 2000). Nugget to sill ratio can better reflect the spatial autocorrelation degree of soil properties data (De Temmerman *et al*., 2003). If NSR is less than 25%, the variable has a strong spatial autocorrelation; if it is between 25%–75%, it has a medium spatial autocorrelation; and its spatial autocorrelation is weak if the degree is greater than 75% (Liu *et al*., 2004). The determination coefficient R^2 is an important basis for the selection of the appropriate model (Jung *et al*., 2006).

2.3.4 Analysis of impact factors on soil characteristics

Canonical correspondence analysis (CCA) (Ter Braak, 1986) is a curve sorting method developed from correspondence analysis, which combines correspondence analysis with multiple regression analysis. At each step of the calculation, regression of dependent variables with environmental factor is performed. In this study, CCA requires two data matrixes: one is the soil properties data matrix, and the other is the matrix of land-use and reclamation time. First, after the soil data matrix is analyzed with detrended correspondence analysis (DCA), if the step length gradient (r) of Axis 1 is larger than 4.0, CCA should be selected; but if r is between 3.0–4.0, redundance analysis (RDA) and CCA are both optional; while if r is less than 3.0, RDA would be better than CCA (Ter Braak, 1986). Then we calculated a group of quadrat sorting values and types of sorting values (the same as correspondence analysis), and combined the quadrat sorting value with environmental factors, using the regression analysis method. In this way, the quadrat sorting value can reflect the quadrat types composition and ecological importance value of soil, and also indicate the impact of environmental factors. Finally, we used the weighted average of quadrat sorting value to represent the soil sorting value, and established an indirect connection between the coordinate value of soil sorting and environmental factors. The algorithm can be realized using Canoco4.5 software (Ter Braak, 1991).

3 Results

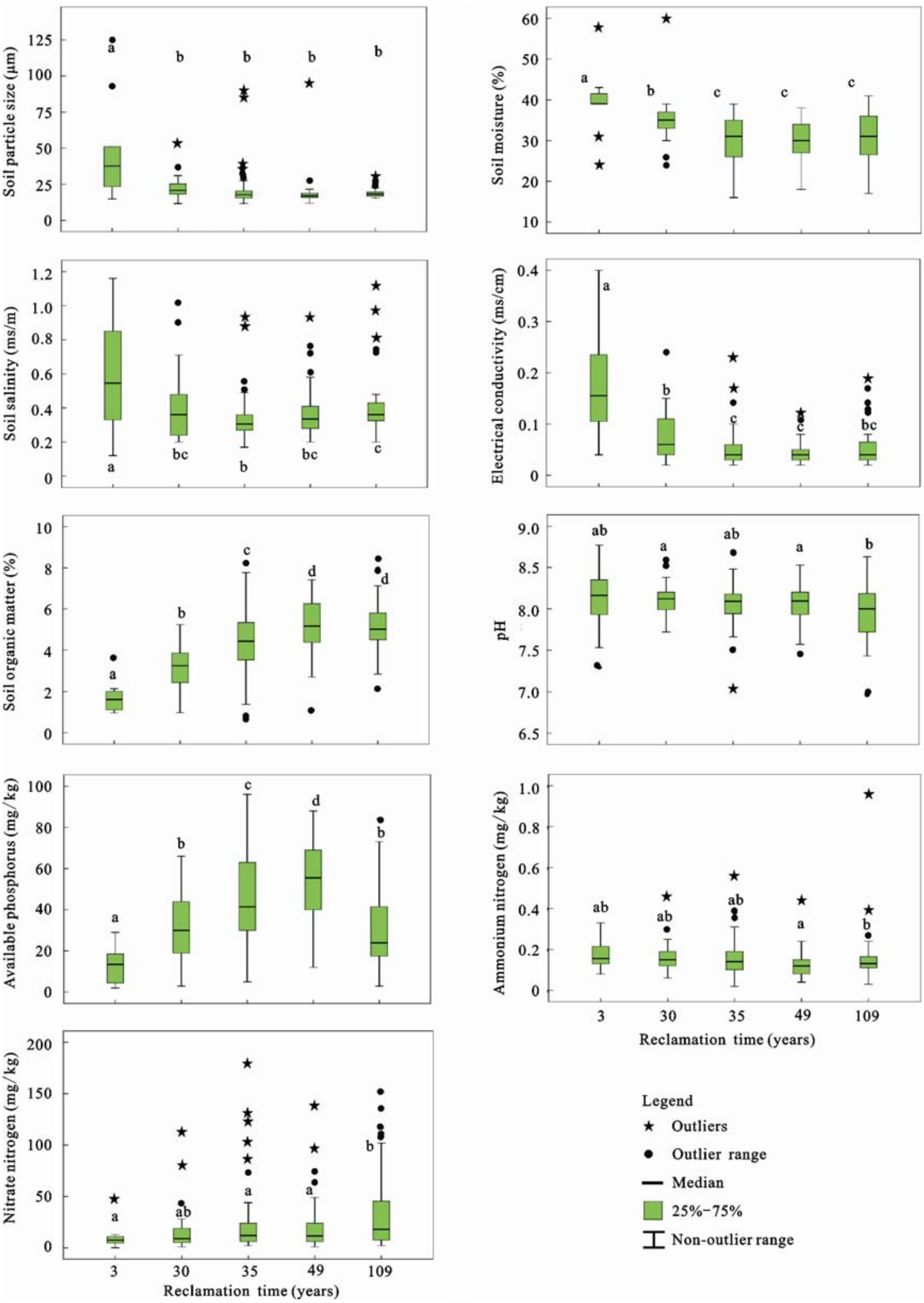
3.1 Temporal differentiation characteristics of soil properties

3.1.1 Tendency of soil physical-chemical properties

Soil properties showed different variation trends in different reclaimed time and land-use types. With the increase in reclamation years, soil moisture, soil salinity, electrical conductivity and soil particle size tended to decline (Fig. 2), while soil organic matter increased; available phosphorus tended to increase in the early reclamation period, while it tended to decline after 49 years of reclamation; nitrate nitrogen, ammonium nitrogen and pH changed slightly in different reclamation zones. The abnormal and extreme values of soil nitrate nitrogen occurred on some samples. In general, soil salinity tended to decline over time, which supports previous studies (Shen *et al*., 2006). We did, however, find that soil salinity tended to increase (from 0.38 to 0.42) during the period of reclamation of 49–109 years (Fig. 2). A relatively higher value of soil salinity occurred, which indicates that soil salinity may increase under certain impact factors.

3.1.2 Variance analysis for soil physical-chemical properties

The results showed that the variables of soil nutrients and F_s value differed significantly ($p < 0.01$) (Table 2) among different reclamation zones. Soil particle size, soil moisture, soil salinity, electrical conductivity and soil organic matter showed significant differences between the early reclamation period (< 30 years) and the middle-later reclamation period (> 30 years) (Fig. 2). Soil particle size and soil moisture became stable after being reclaimed for 30 years. There was no significant difference in soil salinity after having been reclaimed for 30 years and 49 years, but there was a significant difference between 109 years and 35 years. Soil organic matter and soil available phosphorus demonstrated significant differences among all reclamation zones, and continuously accumulated with the increase of reclamation time. Nitrate nitrogen, ammonium nitrogen and pH showed a slight difference in significance between the early reclamation period and in the middle-later reclamation period, which indicated that apart from the factor of reclamation time, it was more influenced by stochastic factors. Soil physic-chemical properties in the early reclamation period were under a continuous process of maturation. Most of them attained a steady state after having been reclaimed for about 30 years, and showed



a, b, c, d: The level of significance was set at $p < 0.01$; the same below

Fig. 2 Statistical analysis of soil properties in different reclamation zones no significant difference after reclamation for 40 years.

3.2 Spatial differentiation characteristics of soil properties

3.2.1 Semi-variance analysis of soil properties for spatial variation factors

Soil organic matter and soil particle size were the best fitting factors (Table 3), whereas the degree of fitting for nitrate nitrogen and ammonium nitrogen was the lowest. The randomness of distribution was probably caused by artificial fertilization. NSR (C_0 / C_0 + C) showed that soil particle size, soil moisture, soil salinity and soil organic matter had a relatively high spatial autocorrelation, which indicated that these indices were profoundly affected by natural processes. Nitrate nitrogen also had a strong spatial autocorrelation, which maybe be caused by systematic error. On the contrary, ammonium nitrogen, available phosphorus and pH showed a relatively low spatial autocorrelation. Therefore the soil variables in the reclamation area can be divided into two groups based on the spatial variation characteristics: 1) variables affected by structural factors (soil particle size, soil moisture, soil salinity and soil organic matter); 2) variables affected by stochastic factors (available phosphorus, ammonium nitrogen, nitrate nitrogen, pH and electrical conductivity).

3.2.2 Spatial characteristics of soil properties

The distribution maps of soil data (Fig. 3) were spatially overlaid with the land use map. Different soil properties had different variation tendencies. Soil particle size, soil moisture, soil salinity, electrical conductivity and pH tended to decline with reclamation time, and were also influenced by land-use types. High values of soil salinity would appear in areas with relatively concentrated arable land (including dry land, irrigated land, greenhouse land, forest land, orchard) (Fig. 3). Soil particle size also differed among different land use types, while it tended to increase in the area with relatively concentrated built-up land. The spatial variation of electrical conductivity was quite similar to that of soil salinity. Soil fertility indices such as soil organic matter, available phosphorus and nitrate nitrogen tended to increase with the increase of reclamation years, but it was also influenced by land-use types. As a result, the higher values of soil fertility indices would appear in areas with relatively concentrated arable land. No trend was found in the spatial variation of ammonium nitrogen.

Soil properties fall into three groups based on the spatial variation characteristics of soil physical-chemical

Table 2 Results of multivariate tests (MANOVA) for soil samples of five reclamation zones

	Test	Value	F_s	Hypothesis *d f*	Error *d f*	sig
Time	Pillai′s trace	0.994	7.57	36	824	0
	Wilks′ lambda	0.269	8.90	36	762	0
	Hotelling′s trace	1.847	10.337	36	806	0
	Roy′s root	1.307	29.919[1)]	9	206	0

Note : The statistic is an upper bound on F_s that yields a lower bound on the significance level

Table 3 Theoretical parameters and models of spatial variability

	Model	Nugget (C_0)	Sill ($C_0 + C$)	Range (A_0) (m)	NSR ($C_0 / C_0 + C$)	R^2	*RSS*
Soil particle size	Spherical	1.22E-03	4.46E-03	5.05E+03	0.22	0.85	4.92E-06
Soil moisture	Exponential	1.01E-02	4.87E-02	8.40E+02	0.21	0.29	6.69E-04
Soil salinity	Exponential	1.75E-02	1.01E-01	2.76E+03	0.17	0.62	3.97E-03
Electrical conductivity	Spherical	1.10E-03	3.00E-03	6.51E+03	0.38	0.75	3.31E-06
Soil organic matter	Spherical	7.69E-01	2.92E+00	3.61E+03	0.26	0.92	8.63E-01
pH	Spherical	3.81E-02	7.63E-02	3.33E+03	0.50	0.62	1.37E-03
Available phosphorus	Exponential	4.35E-02	1.03E-01	2.55E+03	0.42	0.58	2.35E-03
Ammonium nitrogen	Exponential	1.21E-02	7.72E-02	4.80E+02	0.16	0.08	3.65E-03
Nitrate nitrogen	Exponential	1.17E-01	2.35E-01	2.49E+03	0.50	0.47	1.22E-02

Notes: Regression coefficient of determination (R^2) passed F test method at significance level of 0.05; NSR: Nugget to Sill ratio; *RSS*: residual sum squares

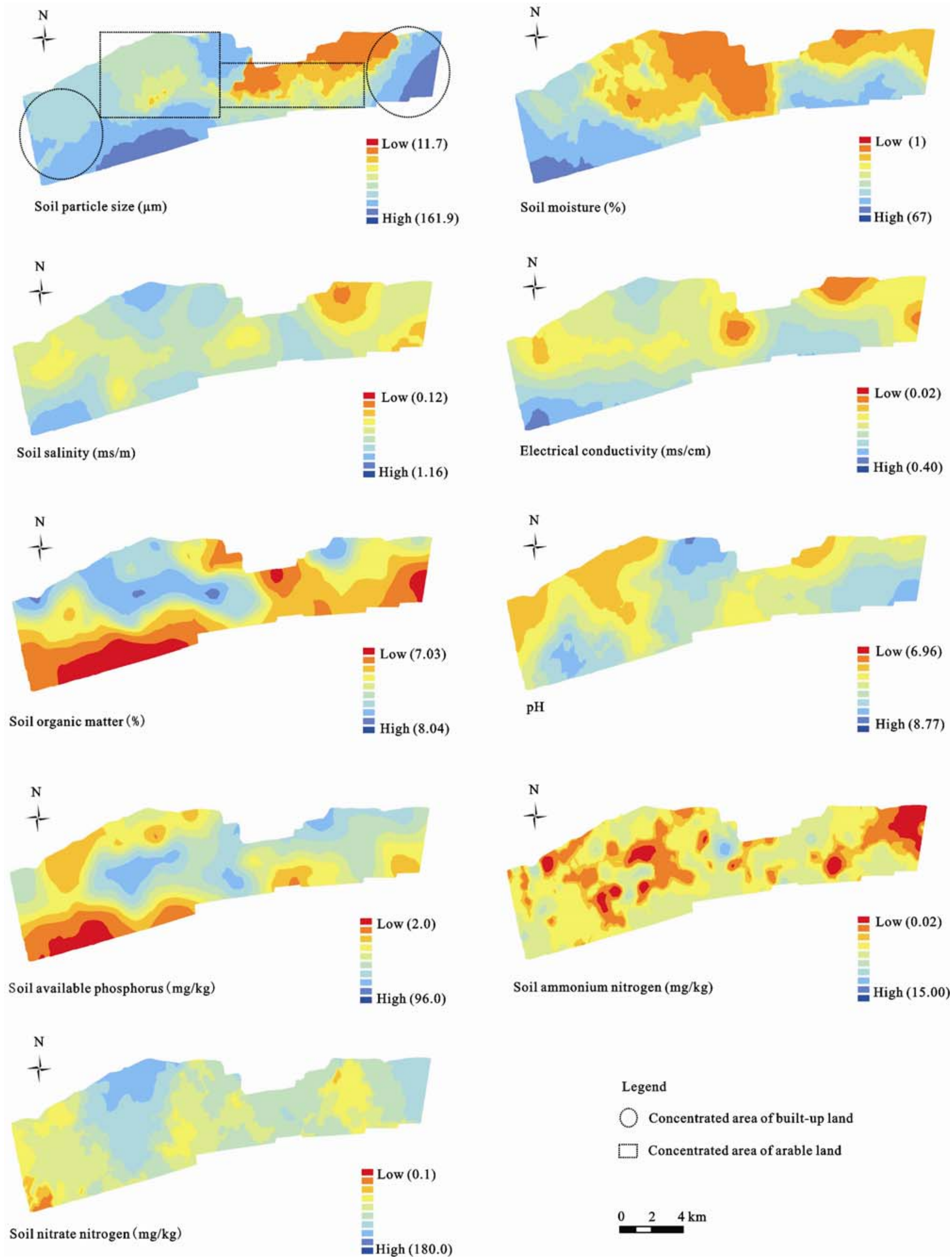


Fig. 3 Spatial variability of soil physical-chemical properties in different reclamation zones

properties:1) negatively correlated with reclamation time (soil particle size, soil moisture, soil salinity, electrical conductivity and pH); 2) positively correlated with reclamation time (soil organic matter, available phosphorus, nitrate nitrogen); and 3) not affected by reclamation time (ammonium nitrogen).

3.3 Comprehensive evaluation of soil functions

The extraction of the principal component should meet two conditions (Yang and Yao, 2009): characteristic root of component > 1; variance contribution > 10. In accordance with the requirements of this study, the accumulated variance contribution (74.9%) of the four extracted principal components should better reflect the information of the study area (Table 4).

Furthermore, PC1 and PC2 reflect 50.9% of the total information amount (Table 4), while PC3 and PC4 reflect 24.1% of the total system information. PC1 was positively correlated with soil organic matter and available phosphorus (Fig. 4); PC2 was negatively correlated with soil moisture, soil salinity, electrical conductivity and pH; PC3 mostly reflected information concerning soil particle size, while nitrate nitrogen and ammonium nitrogen were effectively reflected by PC4. Based on the above analysis, PCA can reflect three aspects of soil properties: 1) soil maturity limiting properties (soil particle size, soil moisture, soil salinity, electrical conductivity and pH); 2) soil nutrient characteristics (soil organic matter and available phosphorus); and 3) soil factors (nitrate nitrogen and ammonium nitrogen) influenced by stochastic factors (human disturbance, farming activities, industrial activities and economic activities). According to the score coefficients of the four principal components, we can obtain the PCA comprehensive evaluation equation of nine soil properties using the score variance contribution of each factor.

$$F = 0.25Z(X_1) + 0.23Z(X_2) + 0.19Z(X_3) + 0.18Z(X_4) + 0.15Z(X_5) + 0.08Z(X_6) + 0.01Z(X_7) - 0.18Z(X_8) - 0.19Z(X_9) \quad (2)$$

where F refers to the comprehensive index of soil function; X_1 is soil salinity; X_2 is ammonium nitrogen; X_3 is available phosphorus; X_4 is soil organic matter; X_5 is electrical conductivity; X_6 is soil moisture; X_7 for nitrate nitrogen; X_8 is pH; X_9 is soil particle size; and $Z(X)$ refers to the standardized score of original soil properties data.

Soil properties can be divided into two groups based on each weighting coefficient in Equation (2): 1) the indices positively correlated to F (soil salinity > ammonium nitrogen > available phosphorus > soil organic matter > electrical conductivity > soil moisture > nitrate nitrogen); and 2) the indices negatively correlated to F (soil particle size > pH). Based on the weighting coefficient of soil maturity limiting factors and soil nutrient factors, we can see that the weighting value (0.97 in total) reflecting soil nutrient factors (ammonium nitrogen, soil organic matter, available phosphorus, nitrate nitrogen, pH and soil particle size) was higher than the weighting value (0.48 in total) of soil limiting factors (soil salinity, electrical conductivity and soil moisture). Therefore, F can better reflect soil quality. The higher the F, the better the soil ecological function. Based on the above analysis, we substituted the standardized data of soil physical-chemical properties into the comprehensive evaluation equation, and obtained a soil func-

Table 4 Total variance explained for soil properties in different reclamation zones (PCA)

Components	Initial eigenvalue			Extraction sums of squared loadings		
	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)
1	2.31	25.66	25.66	2.31	25.66	25.66
2	2.27	25.24	50.89	2.27	25.24	50.89
3	1.10	12.22	63.11	1.10	12.22	63.11
4	1.07	11.86	74.98	1.07	11.86	74.98
5	0.63	7.03	82.01			
6	0.55	6.15	88.16			
7	0.49	5.48	93.63			
8	0.30	3.37	97.00			
9	0.27	3.00	100.00			

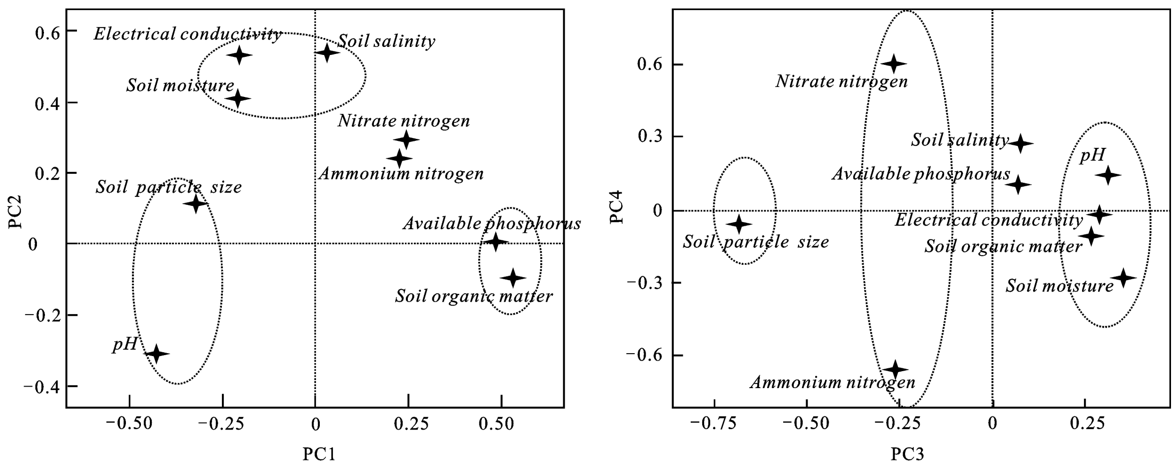


Fig. 4 PCA ordinations of soil properties with PC1, PC2, PC3 and PC4 in study area

tion F-value of 216 sampling points in the study area. Using the K-S test, the data was found to conform to the normal distribution.

3.4 Temporal and spatial differentiation characteristics of soil *F*-value

The differentiation of the comprehensive index of soil functions (*F*-value) in different reclamation years is shown in Table 5. The variance indicated that the difference in *F*-value reaches a maximum level in the early reclamation period (3 years) (Table 5); nevertheless, the difference was small in the middle of the reclamation period (30, 35 and 49 years). When soil was in its natural condition in the early reclamation period, the difference was relatively high. With the increase in reclamation years, however, soil is gradually transitioned to maturity status. In addition, when it came to the later reclamation period (109 years) and land use types were gradually changed from natural land and arable land to built up and industrial land, the soil functions index showed a significant difference. The results showed that *F* tended to increase with the increase of reclamation years. It was, however, also affected by land use types.

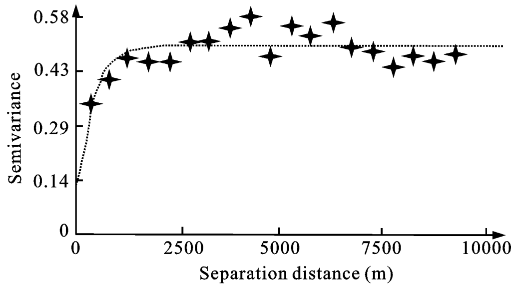
F had a strong spatial autocorrelation (C_0 / (C_0 + C) = 0.18), which indicated that the soil functions index was mainly influenced by structural factors (soil parent material, terrain, reclaimed time, *etc*.), and some stochastic factors (artificial fertilization, building and business activities) (Fig. 5). This was comparable with the PCA results. The comprehensive index of soil functions *A*0 was 370 m (relatively low). With an exponential model to verify the spatial interpolation analysis of *F*, it is indicated that although *F* increased with the increase in reclamation time, higher *F* values concentrated spatially (Fig. 3, Fig. 6). In the same reclamation area, *F* in concentrated arable land was higher than that in other areas with the same reclamation time. However, *F* (30 years, 35 years, 49 years and 109 years) in the area with concentrated residential land was lower than that in other adjacent areas.

With the change in reclamation years, *F* showed different variation characteristics in different land use types. The *F* for greenhouse land, dry land, irrigated land, forest land and orchard tended to increase (Fig. 7); while that for the aquaculture pond tended to decline. Unutilized land, grassland generally had a negative ef-

Table 5 Statistical summary of descriptive analyses for *F* value of study area

Years	Samples	Average	Variance	± S.D.	Max	Min	Skewness	Kurtosis	CV (%)
3	12	–0.26ab	1.34	1.16	1.60	–2.37	–0.24	–0.55	–4.53
30	24	–0.16a	0.63	0.79	1.45	–1.60	0.25	–0.61	–4.85
35	95	–0.08a	0.39	0.63	1.74	–2.18	–0.06	2.27	–7.55
49	50	0.14ab	0.37	0.60	1.69	–1.40	0.32	0.95	4.40
109	35	0.23b	1.07	1.04	3.71	–1.17	1.66	2.85	4.53

Notes: a, b following the mean values indicate statistical separation, with columns in MANOVA followed by LSD; the mean difference is significant at the level of 0.05



Exponential model (C_0 = 0.054; $C_0 + C$ = 0.501; A_0 = 370; R^2 = 0.472; *RSS* = 0.0296)

Fig. 5 Semivariance of soil function index (*F*) for 216 sampling points under active lag distance (10000 m) and lag class distance interval (500 m)

fect on the enhancement of soil functions, and *F* tended to decline with the increase in reclamation time (Fig. 7). Based on the effects of different landscapes on the maturity process of soil functions (*F*), the land use types can be divided into three groups: 1) land use types (greenhouse land, dry land, irrigated land, forest land and orchard) that facilitate the enhancement of soil functions; 2) land use types that restrict the enhancement of soil functions (aquaculture ponds, grassland, unutilized land); and 3) land use types (mudflat, built-up land and open water) that have no profound effects on the enhancement of soil functions.

3.5 Analysis of impact factors on soil function

Soil physical-chemical properties were mainly influenced by reclamation time, and then land use types (Fig. 8a). The correlation absolute value (R = | 0.1905 |) of *F* and reclamation time was greater ($p < 0.01$) than that of *F* and land use types (R = | –0.1161 |), which indicated that soil function maturity was mainly influenced by reclamation time. A CCA T-value sorting chart (Fig. 8b) can better demonstrate the relationships between the impact factors and soil physical-chemical properties. Reclamation time was positively correlated with soil organic matter and ammonium nitrogen, while it was negatively correlated with soil moisture, electric conductivity, soil salinity, available phosphorus and nitrate nitrogen. Available phosphorus and nitrate nitrogen were greatly influenced by land use types, and therefore they were negatively correlated to reclamation time (This differs from GA, which presents the spatial distribution. CCA only presents the patterns based on the statistics from sampling points). *F* was negatively correlated to pH and soil particle size, and positively correlated with other indices.

4 Discussion

In our study, we found that the differentiation of soil physical-chemical properties in the reclamation area was influenced by reclamation time, and soil physical-chemical properties were close to the stable state after having been reclaimed for about 30 years, which is similar to the findings of other studies (Shen *et al*., 2006; Wu *et al*., 2008). But our results on salinity differ

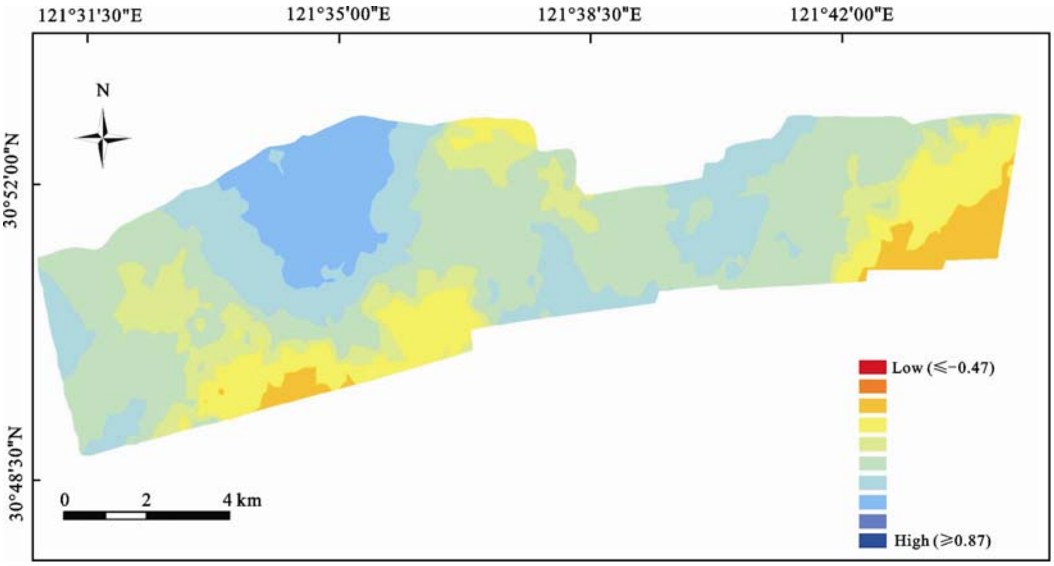
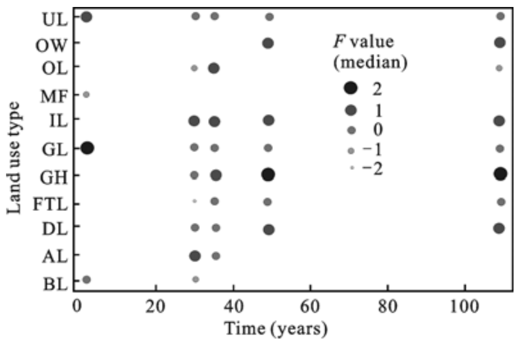


Fig. 6 Kriging interpolation based exponential model for soil function index (*F*) of 216 sampling points in different reclamation zones



UL: unutilized land; OW: open water; OL: orchard; MF: mudflat; IL: irrigated land; GL: grassland;
GH: greenhouse land; FTL: forest land; DL: dry land; AL: aquaculture pond; BL: Built-up land

Fig. 7 Distribution of soil function index (F) against different land use types and different reclaimed time

slightly from other research results (Li and Shi, 2005). Our salinity first appears to decline, and then locally tends to increase, after being influenced by stochastic factors, e.g., land use types, while Li and Shi (2005) found that soil salinity declined consecutively with reclamation time. Suitable policies should be adopted to prevent salinity enrichment in the future management of reclamation areas. In general, anthropic process (such as fertilization, tillage measures and cropping system) are extrinsic factors affecting the variation of soil characteristics, which show greater randomness, for example, ammonium nitrogen showed extreme value (Fig. 3), which might be caused by experimental error or other stochastic factors, and the structural property and correlation of spatial variation would produce a weakened effect, to make the spatial distribution of soil properties develop in a uniform direction (Liu *et al*., 2004).

Furthermore, we found that the spatial differentiation of soil nutrients is influenced by land use types. Soil nutrient factors in areas with concentrated arable land tended to increase, while its soil limiting factors tend to decline. This would probably cause strong spatial differentiation of soil nutrients in the same reclamation zone, and this result is identical with the conclusion of 'spatial differentiation of soil surface nutrients and salinity due to different land use patterns in the reclamation area' of Li and Shi (2005). This paper performed further research and found that different land use types play different roles in the maturity of soil functions, which provides a decision-making basis for the management of land use patterns in the reclamation area. In the early reclamation period, aquaculture ponds can be properly developed. However, after having been reclaimed for 10 years, the development and utilization of farm lands should be encouraged, because farm lands are beneficial for soil maturity. The development scale of unutilized land, grassland and aquaculture pond should be correspondingly reduced, since they are not beneficial to soil maturity.

Some studies (Wu *et al*., 2008; Hu *et al*., 2009) also found that soil compaction and soil nutrients were influenced by reclamation time. The authors did not, however, find the quantitative relationships between the

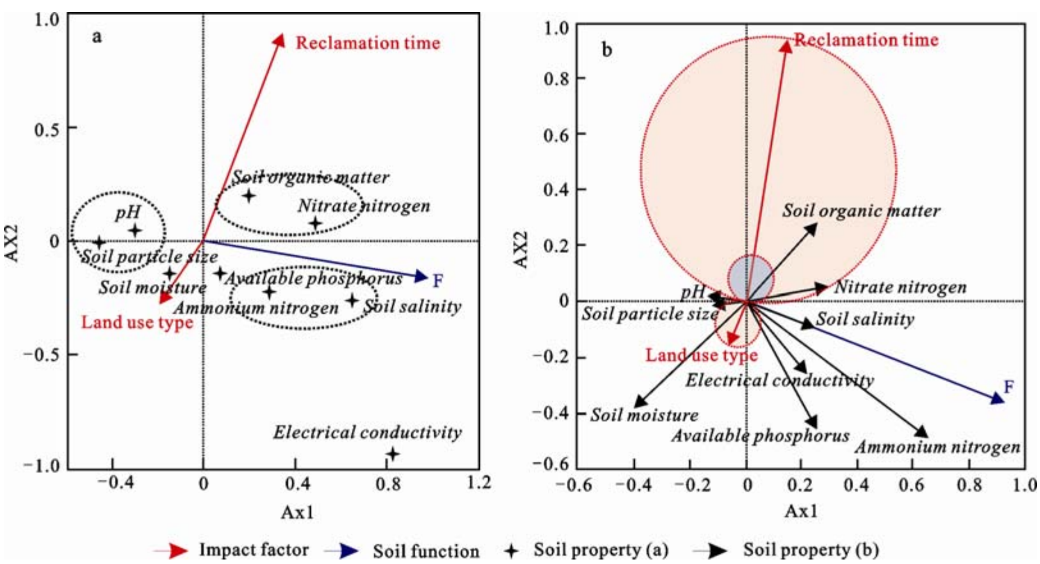


Fig. 8 CCA ordination of soil properties (a) and T-value ordination (b) of soil properties between reclamation time and land use

two factors. This paper found that the time after reclamation has much effect on soil physical-chemical properties than land use types in the reclamation area. In addition, the research showed that the differentiation level of soil functions in the reclamation area was influenced by both structural factors and stochastic factors, which is identical with earlier conclusions by other authors (Yang and Yao, 2009).

5 Conclusions

The results of this study showed that reclamation time and land use types were the key impact factors on soil physical-chemical properties and soil function in reclamation zones. The comprehensive evaluation index (F) of soil functions constructed by PCA can better reflect the comprehensive soil level of the reclamation area, and the quantitative relationships between soil differentiation, reclamation time and land use types can be better reflected using the CCA method. The information content reflected by the PCA method may, however, be affected by the indices selected.

These findings can be applied to similar spatial scales of coastal reclamation areas. However, its application at larger spatial or temporal scales still needs further discussion. The relations of vegetation-community characteristics, economic functions and landscape patterns in the reclamation area have not been analyzed in this study, and will be emphasized in future research.

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