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The Assessment of Soil Quality on the Arable Land in Yellow River Delta Combined with Remote Sensing Technology

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Abstract

Soil quality assessment is essential to improve the understanding of soil quality and make proper agricultural practices. However, soil quality assessments are extremely difficult to implement in a large-scale area, since they are time and labor consuming. Remote sensing technique gained more attention in plant and soil information monitoring recently for its high efficiency and convenience. But seldom studies tested the applicability of remote sensing techniques before implementing. This study conducted the soil quality assessment in a typical agricultural county in the Yellow River delta (Kenli). We found the soil quality in Kenli was dominantly in the low grade (71.85%), with deficient nutrient (SOM and TN), poor structure (high BD) and high EC. Salinity is the primary limiting factor for soil quality in Kenli, and adjustment of soil salinization through suitable farming practices such as organic fertilizers application, irrigation for leaching, and salt-tolerant crop planting is the key point for soil quality improvement. We obtained the normalized difference vegetation index (NDVI) of the study area by remote sensing technique, and found the high correlation between NDVI and soil quality indicator (SOM, TN and EC) and yield. The NDVI can help to study the soil conditions as a soil quality assessment indicator. More studies about the application of remote sensing technique on soil quality detecting are expected.

Keywords

NDVI, Remote Sensing Technology, Soil Quality Indexing, Soil Quality Indicators

1. Introduction

Soil quality can be defined as “the capacity of soil to function to sustain plant and animal productivities, to maintain or enhance water and air quality and to support human health and habitation" [1]. An understanding of soil quality is important to identify problem areas, provide early warning signs of adverse trends, and make sustainable agricultural management [2] [3].

Improved understanding of soil quality comes from a reliable and accurate soil quality assessment, which is a decision-making tool that effectively combines a variety of soil information to analyze quantitatively the soil conditions. Soil quality indexing is the most commonly used method, as it is easy and flexible to use [4] [5], and hence, it was chosen to assess the soil quality in the present study. Appropriate indicators choosing is the primary step during soil quality indexing. Physical, chemical, and biological characteristics of the soil that can influence soil production and are sensitive to environmental changes are typically chosen as soil quality indicators [6]. However, experimental analyses of numerous assessing indicators are extremely difficult to implement in a large-scale area, since they are time consuming, laborious and expensive. Consequently, new methods need to be developed with the aims of enhancing work efficiency and reducing labor, time, and expense. Recently, increasing studies monitored plant and soil information such as soil moisture, temperature, and plant cover by means of remote sensing techniques [7] [8]. Compared with traditional experimental analyses, remote sensing techniques are more efficient and economical, and also can offer the data continuously. However, spectral reflectance is influenced by many factors, especially of soil and plant types. Applicability of remote sensing techniques for a specific soil or area is uncertain. More studies on soil quality information detecting based on remote sensing techniques for different growing areas are required.

Yellow River delta is one of the primary growing regions in China with Fluvisol being the main agricultural soil type. However, limiting factors such as nutrient deficiency, structural degeneration, and land desertification have been reported for soils in Yellow River delta [9] [10]. Therefore, it is challenging to understand the soil quality on the Fluvisol in the Yellow River delta.

The present study assessed the soil quality of a typical agricultural county (Kenli) in the Yellow River delta, and analyzed the limiting factors of soil quality based on the assessment result. In addition, the applicability of remote sensing technique on soil quality assessment studies was tested.

2. Material and Methods

2.1. Site Description and Soil Sampling

The experiment was conducted in the typical agricultural county in Yellow Riverdelta, Kenli (118˚24' - 119˚10'E, 37˚21' - 38˚9'N) (**Figure 1**). Kenli County has a warm, temperate, semi-humid monsoonal climate, with an average annual air temperature of 11.9˚C and an average rainfall of 592.2 mm. The soil in Kenli is classified as Salic Fluvisol, according to the FAO-UNESCO system. Andthe main crop in Kenli is cotton.

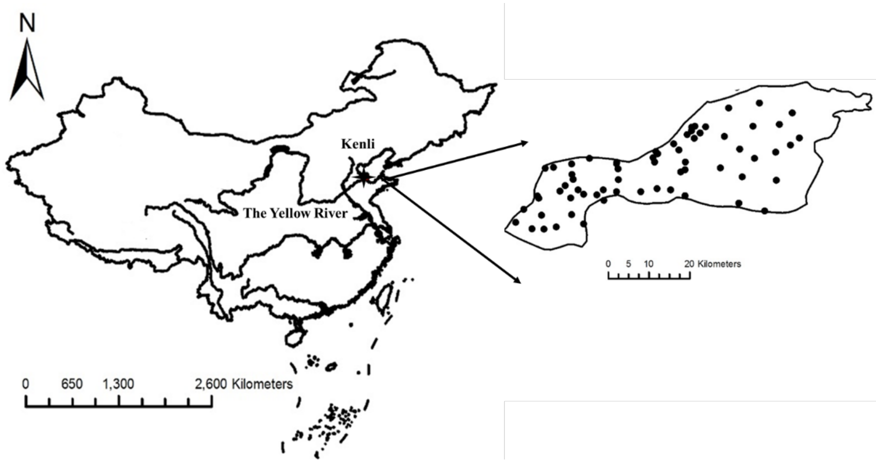

Figure 1. The study area and sampling points.

2.2. Soil Sampling and Laboratory Analyses

Soil samples were collected after harvest and before the next cropping season. The sampling points in Kenli are shown in **Figure 1**. Each soil sample was a composite of 4 subsamples and taken from a soil depth of 0 - 20 cm in the field. A total of 70 samples were collected, and the geographical positions were recorded using a handheld GPS. After sampling, soil samples were stored in plastic bags for laboratory analyses. Methods of soil characteristics determination were listed in **Table 1** [11].

2.3. Remote Sensing Data Acquisition and Processing

The moderate-resolution imaging spectroradiometer (MODIS) is a payload scientific instrument that is on board the NASA's Terra and Aqua satellites. This study used the MOD09 data which comes from the land surface reflectance product developed by the NASA MODIS. MOD09 data is the level 2 dataset, with the spatial resolution of 250 m and time resolution of 1 day. After the atmospheric, geometric and radiation corrections, the normalized vegetation index (NDVI) can be calculated based on the MODIS data of 1 - 7 bands (620 - 670, 841 - 876, 459 - 479, 455 - 565,1230 - 1250, 1628 - 1652, 2105 - 2155). This study calculated the NDVI of Kenli with a scene remote sensing image on September 11before harvest. NDVI mainly reflects plant canopy status, and usually be used to detect vegetation growth and vegetation coverage. The calculation equation is

$$\text{NDVI} = (\text{Band } 2 - \text{Band } 1) / (\text{Band } 2 + \text{Band } 1) \tag{1}$$

where, the Band 1 is the first band, Band 2 is the second band, and the range of NDVI was between −1 to 1.

2.4. Soil Quality Assessment Methods

Soil quality indexing normally includes three steps: 1) choosing appropriate indicators, 2) scoring the indicators, and 3) combining the indicator scores into an

Table 1. Methods of soil characteristics determination.

Soil quality indicator	Method
Soil organic matter (SOM)	Walkley-Black method
Total nitrogen (TN)	Kjeldahl digestion method
Available phosphorus (AP)	Extracting-spectrophotometer detection
Available phosphorus (AK)	Extracting-flame photometry detection
pH	Electrometric method
Dry bulk density (BD)	Core method
Clay %	Pipette method
Electrical conductivity (EC)	Conductivity meter

index. In the present study, eight soil characteristics (SOM, TN, AP, AK, BD, EC, Clay%, and pH), which can influence the functions of carbon transformations, soil nutrient cycles, structure maintenance and buffer capacity, were considered as indicators.

During the scoring of indicators, the values of indicators were transformed into appropriate scores (0 - 1) through the linear scoring methods, since indicators are expressed with different numerical scales. Based on the indicator sensitivity, three types of functions were developed: 1) a "more is better" function (M), 2) a "less is better" function (L), and 3) an "optimal range" function (R) (**Table 2**).

After indicator scoring, indictor scores were transformed to a soil quality index. To calculate the soil quality index (SQI), soil quality indicators should be weighted. In the present study, the weight value of each indicator was assigned by the communality value through factor analysis (IBM, SPSS Statistics 20.0) (**Table 3**). The equation used to calculate SQI can be seen in Equation (2):

$$\mathrm{SQI} = \sum_i^n W_i N_i \tag{2}$$

where, SQI is the soil quality index; W_i is the weight of the indicator; and N_i is the score of the indicator.

2.5. Soil Quality Classification and Spatial Variability Analysis

Soil quality was divided into five grades: very high (SQI ≥ 0.85), high (0.85 > SQI ≥ 0.7), moderate (0.7 > SQI ≥ 0.55), low (0.55 > SQI ≥ 0.4), and very low (SQI < 0.4), according to the classification criteria [12]. Spatial variability analysis of soil quality was carried out using geostatistical analysis software (ArcGIS 10.2). The interpolation method used was the inverse distance weighting.

3. Results and Discussion

3.1. Soil Characteristics in Kenli

Eight representative soil characteristics were functioned as indicators to evaluate

Table 2. Linear scoring functions and indicator parameters.

Indicator	Type	x_1	x_2	Function
SOM (g·kg^{-1})	M (x)	6	20	$M(x)=\begin{cases}0.1 & x<x_1\\ 0.9\times\frac{x-x_1}{x_2-x_1}+0.1 & x_1<x<x_2\\ 1 & x>x_2\end{cases}$
TN (g·kg^{-1})	M (x)	0.3	1.2	
AP (mg·kg^{-1})	M (x)	5	15	$L(x)=\begin{cases}1 & x<x_1\\ 1-0.9\times\frac{x-x_1}{x_2-x_1} & x_1<x<x_2\\ 0.1 & x>x_2\end{cases}$
AK (mg·kg^{-1})	M (x)	40	200	
EC (mS·cm^{-1})	L (x)	0.2	4	$R(x)=\begin{cases}0.1 & x<x_1\\ 0.9\times\frac{x-x_1}{r_1-x_1}+0.1 & x_1<x<r_1\\ 1 & r_1<x<r_2\\ 1-0.9\times\frac{x-r_2}{x_2-r_2} & r_2<x<x_2\\ 0.1 & x>x_2\end{cases}$
BD (g·cm^{-3})	L (x)	1.25	1.55	
Clay %	R (x)	5	40	
pH	R (x)	5.5	9.5	

Where, x is the measured value of the indicator; M(x), L(x), and R(x), are "More is better", "Less is better", and "Optimal range" scoring functions; x_1 and x_2 are the lower and the upper threshold values, respectively; and r_1 and r_2 are the lower and the upper values of the optimal range, respectively.SOM, soil organic matter; TN, total nitrogen; AP, available phosphorus; AK, available potassium; EC, electrical conductivity; BD, bulk density.

Table 3. Weight values of soil quality indicators.

Indicator	Weight
SOM (g·kg^{-1})	0.14
TN (g·kg^{-1})	0.15
AP (mg·kg^{-1})	0.07
AK (mg·kg^{-1})	0.10
EC (mS·cm^{-1})	0.16
BD (g·cm^{-3})	0.12
Clay %	0.10
pH	0.16

SOM, soil organic matter; TN, total nitrogen; AP, available phosphorus; AK, available potassium; EC, electrical conductivity; BD, bulk density.

the soil quality in Kenli. **Table 4** shows the mean, standard deviation, and range of indicators. Soil nutrients in Kenli were deficient, as they had lower SOM (9.97 ± 3.90) and TN (0.63 ± 0.23). But for AP and AK, the values were relatively higher, deficiency were only observed at some sampling points. Based on the pH (8.13 - 9.20), soils were classified as slightly alkaline. The soil texture is loamin Kenli based on the clay%, but the high BD suggested soil structure, especially of aeration, was poor. It is noted that soil EC values observed in Kenli were significantly high, with a mean value of 1.37 mS·cm^{-1}. Kenli located in the Yellow River delta

Table 4. Descriptive statistics of the soil quality indicators in Kenli.

Indicator	Mean	Range
SOM ($g \cdot kg^{-1}$)	9.97 ± 3.90	3.25 - 21.73
TN ($g \cdot kg^{-1}$)	0.63 ± 0.23	0.22 - 1.28
AP ($mg \cdot kg^{-1}$)	19.04 ± 16.13	3.31 - 86.63
AK ($mg \cdot kg^{-1}$)	159.13 ± 61.93	76.84 - 379.12
EC ($mS \cdot cm^{-1}$)	1.37 ± 1.41	0.11 - 7.01
BD ($g \cdot cm^{-3}$)	1.48 ± 0.13	1.05 - 1.69
Clay %	17.53± 8.82	2.26 - 44.92
pH	8.78 ± 0.23	8.13 - 9.20

SOM, soil organic matter; TN, total nitrogen; AP, available phosphorus; AK, available potassium; EC, electrical conductivity; BD, bulk density.

that borders the Bohai Sea, and the high soil salinity responded to a high EC. Excess salt in soils causes clay particles to disperse or swell, and consequently, these soils have poor structure with low aggregate stability, aeration, and water infiltration. Moreover, saline soils are a poor rooting medium for nutrients providing and plant growth, which leads to low quality level [13] [14]. Therefore, salinity is the primary limiting factor for soil quality in Kenli. A considerable variability was observed for the soil indicators of AP, AK, EC and Clay%.

3.2. Soil Quality Assessment in Kenli

The soil quality in the studied areas was classified into five grades—very high, high, moderate, low, or very low. Soil areas in the low grade were dominant, with the area of 71.85% (**Figure 2**). And then is the moderate grade (25.52%). In high and very high grades, soil areas were limited with 0.21% and 0%, respectively.

The main factors that influenced soil quality included climate, topography, soil type, plant species, and agricultural management. In Kenli, both agricultural management and geographical position were the major influencing factors, since salinization is an important determinant of soil quality. Adjustment of soil salinization through suitable farming practices is the key point for soil quality improvement. The improvement management may include: 1) increasing organic fertilizers application, 2) lands leveling, 3) residue covering, 4) irrigation for salinity leaching, 5) chemical conditioner application, and, 6) salt-tolerant crop planting [15] [16]. Intensive agricultural production began to flourish in China since the 1980's. Soil degrading occurred in most of farmland due to extensive chemical fertilizer application and frequent tillage. Therefore, unappropriated agricultural management is also an influencing factor of soil quality sustainability. Adopting appropriate agricultural management (*i.e.* conservation tilling, precise fertilization) aiming to improve soil quality based on assessment result is necessary.

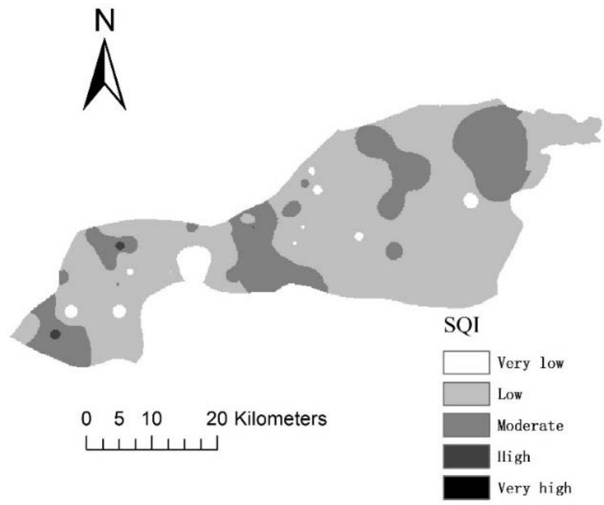

Figure 2. Distribution of soil quality in Kenli.

3.3. Applicability of Remote Sensing Technique on Soil Quality Assessment

The normalized difference vegetation index (NDVI) of the study area was obtained by remote sensing technique (**Figure 3**), which could help to study the crop growing and soil condition. As shown in **Table 5**, correlations between NDVI and soil characteristics as SOM ($R = 0.38$, $P < 0.01$, $n = 70$), TN ($R = 0.37$, $P < 0.01$, $n = 70$), and EC ($R = -0.41$, $P < 0.01$, $n = 70$) were observed, suggesting NDVI can reflect the soil conditions well. Since assessing of soil quality in the present study was conducted on farmland, aiming to understand soil conditions and improve crop production, correlations between the indicator and crop yield should also be full considered during assessing. High correlation between NDVI and yield ($R = 0.36$, $P < 0.01$, $n = 70$) was also found in the present study (**Table 5**). NDVI obtained by remote sensing explained the crop production well, and showed high correlation with the main soil characteristics (SOM, TN and EC); therefore, can be considered as an indicator to apply on soil quality assessment. Compared with traditional experimental analyses, remote sensing techniques are more applicability for the large-scale study for its data obtaining fast and conveniently. In the future study, more important soil information derived from remote sensing techniques is expected.

4. Conclusions

To understand the soil quality in Yellow River delta, soil quality assessment was conducted in a typical agricultural county of Yellow River delta, Kenli. The assessment result showed the soil quality in Kenli was dominantly in the low grade, because of nutrient deficiency (especially of SOM and TN), poor structure and salinity. Salinity is the primary limiting factor for soil quality in Kenli, which was influenced by agricultural management and geographical position.

Applicability of the normalized difference vegetation index (NDVI) obtained by remote sensing technique was tested as a soil quality indicator. We found

Table 5. Relationships among NDVI, soil characteristics, soil quality index and yield.

	NDVI	SOM ($g·kg^{-1}$)	TN ($g·kg^{-1}$)	AP ($mg·kg^{-1}$)	AK ($mg·kg^{-1}$)	EC ($mS·cm^{-1}$)	BD ($g·cm^{-3}$)	Clay %	pH	SQI	Yield ($kg·ha^{-1}$)
NDVI	1.00	0.38**	0.37**	0.11	0.01	−0.41**	0.02	0.02	0.24	0.39**	0.36**
SOM ($g·kg^{-1}$)		1.00	0.81**	0.20	0.36**	−0.22	0.02	0.22	−0.15	0.81**	0.44**
TN ($g·kg^{-1}$)			1.00	0.26*	0.45**	−0.24*	0.03	0.34**	−0.21	0.86**	0.43**
AP ($mg·kg^{-1}$)				1.00	0.16	−0.15	−0.05	0.10	−0.12	0.34**	0.20
AK ($mg·kg^{-1}$)					1.00	0.21	−0.03	0.12	−0.20	0.44**	0.45**
EC ($mS·cm^{-1}$)						1.00	−0.18	−0.19	−0.61**	−0.48**	−0.20
BD ($g·cm^{-3}$)							1.00	−0.11	0.09	0.17	−0.01
Clay %								1.00	−0.07	0.33**	0.06
pH									1.00	−0.04	0.08
SQI										1.00	0.53**
Yield($kg·ha^{-1}$)											1.00

SOM, soil organic matter; TN, total nitrogen; AP, available phosphorus; AK, available potassium; EC, electrical conductivity; BD, bulk density; NDVI, the normalized difference vegetation index; SQI, soil quality index.

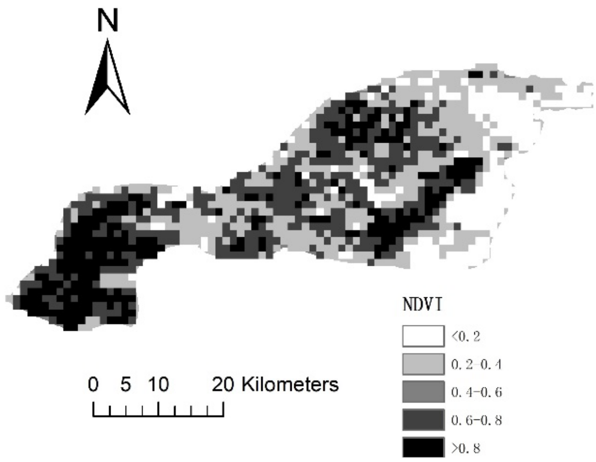

Figure 3. The normalized difference vegetation index (NDVI) obtained by remote sensing in Kenli.

NDVI can reflect the soil conditions and explain the crop production well. Considering the remote sensing technique can also obtained information efficiently and conveniently, application of remote sensing techniques on more soil quality studies is expected.

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