Application of GIS technique in the fertility assessment of tropical farmland: A case study of Bayi Farm areas of Hainan Island, China

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***Abstract*—Explore the distribution of soil fertility and soil nutrients is significant to the sustainable development of tropical agricultural growth. Take Bayi farm areas in Hainan province as the study area, exploring the distribution of soil fertility and nutrients in research area by applying the GIS spatial analysis tools and fuzzy mathematical theory. The results showed that the concentrations of soil organic matters, total N, available P, and available K are in moderate levels but unevenly distributed in study areas. The soil of farmland is acidic, and the value of pH is 4.8. The distribution of soil fertility is mainly determined by topography of farmland, and the higher fertility of farmland mainly distributed in areas which slope below 8°. The tools of spatial analysis can be applied in soil fertility assessment, as well as can present the spatial distribution of soil fertility. It is significant to improve the soil fertility of farmland.**

Keywords-GIS; Nutrients; Fertility; Farmland; Hainan

I. INTRODUCTION

Farmland is fundamental to agricultural production. The per capita arable land shares only 44 percent of the world [1] in China, while that of Hainan Island is even lower than this level. Due to Hainan Island is the production base of tropical agricultural products, the quality of farmland soil, especially the soil fertility of rubber plantations is concerned by agriculture scientists.

The chemical fertilizers were excessively applied in farmland owing to the deficiency of farmland resources [2], which can cause the variation of nutrients distribution in farmland soil and lead to decreasing of the quality and yield of agricultural products [3]. The fertility assessment of farmland soil was the basic research work for increasing utilization ratio of fertilizer and improving the yields and quality of agricultural products [4]. The objective of this study was providing basis for agricultural planning of Hainan province by taking Hainan Bayi Farm areas as the study area and applying the spatial analysis tools to analyze the distribution of soil nutrients and soil fertility.

II. MATERIALS AND METHODS

A. *Study area*

Bayi farm area is located within the territory of Danzhou, 19°19′36″-19°51′48″ N, 109°3′48″-109°46′55″ E, covering 995.77 km^2 (99577 hm^2) (Figure 1). There are 10 farms in Bayi farm area, which named Xipei, Xihua, Xiqing, Xilian, Xiliu, Lanyang, Xinying, Hongling, Longshan and Bayi fram.

The average annual precipitation and temperature is 900-2000 mm and 23.5℃,respectively. It indicated that this area has favorable aqua-therm conditions for tropical agricultural production, in particular to that of rubber products.

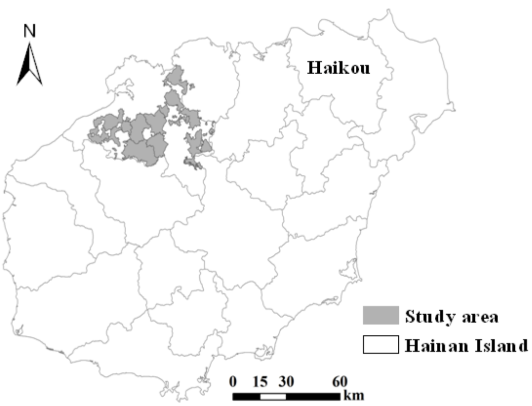

Figure 1. Study area

B. *Sampling and analytical work*

Soil samples were collected in the cultivated layer of farm land (0-20cm) in 2010. A composite soil sample was collected from each sample site. All the soil samples were taken back to the laboratory, air-dried at room temperature after removing the plant roots and stones, and then pass through less than 2 mm sieve.

A total of 2635 soil samples were obtained for laboratory analysis. The contents of total N, available P, available K, organic matters and soil pH were determined following the methods of Lu [5].

C. *Statistical analysis*

All statistical analyses were performed using the SAS Systems for Windows 9.00. The spatial distribution of soil fertility was obtained by ArcGIS spatial analysis tools.

D. Soil fertility assessing method

The assessing indicators include organic matters, total N, available P, available K, soil pH, soil bulk density, annual precipitation, parent materials, degree of slope and cultivating layer thickness. There are five types of membership function, which are efficiency type, cost type, bell shaped type, liner type and concept or discrete type.

The membership functions of selected assessing indicators in this study fall into four categories. The membership degrees of each indicator can be calculated by their membership functions (Table I). The membership degrees of concept or discrete indicators are estimated by the Delphi Method (Table II). The weight of each assessing indicator was determined by Analytic Hierarchy Process method (Figure 2) [6].

TABLE I. THE pH AND NUTRIENTS CONTENTS IN SOIL SAMPLES

	Membership function	*c*	u_t	Type
Precipitation	$y= (1+2.86\times10^{-6}(u-c)^2)^{-1}$	1900	1200	Efficiency
Available P	$y= (1+0.0013\times(u-c)^2)^{-1}$	34.77	3	Efficiency
Organic matters	$y= (1+0.0024\times(u-c)^2)^{-1}$	33.24	6	Efficiency
Available K	$y= (1+0.0001\times(u-c)^2)^{-1}$	200	20	Efficiency
Total N	$y= (1+0.8397\times(u-c)^2)^{-1}$	1.97	0.25	Efficiency
Soil bulk density	$y= (1+7.6785\times(u-c)^2)^{-1}$	1.19	1.6	Cost
Soil pH	$y= (1+0.3793\times(u-c)^2)^{-1}$	5.15	u_{t1}=3.5 u_{t2}=7.5	Bell shaped

TABLE II. MEMBERSHIP DEGREE OF CONCEPT OR DISCRETE INDICATORS

	Description	Membership Degree
Cultivating layer thickness (cm)	< 30	0.09
	30-50	0.18
	50-70	0.3
	70-90	0.46
	90-110	0.66
	110-130	0.86
	130-150	0.95
	>150	1
Degree of slope (°)	<3	1
	3-7	0.96
	7-15	0.89
	15-20	0.78
	20-25	0.62
	25-30	0.35
	30-35	0.17
	>35	0.08
Parent materials	a†	0.92
	b	0.87
	c	0.80
	d	0.74
	e	0.68
	f	0.58
	g	0.48

† a: River alluvium, b: Arenaceous shale weathering material, c: Granite weathering material, d: Metamorphic rock, e: Basalt, f: Limestone, g: Neritic sediments

Soil productivity of each assessing plots of farmland can be obtained by weight sum all of membership degrees of assessing indicators. The calculation method is as Eq. 1:

$$IFI=\Sigma F_i \times C_i \quad (1)$$

Where: *IFI* is the fertility of farmland; F_i is the membership degree of assessing indicator; C_i is the comprehensive weight of assessing indicator. The value of *IFI* can present the soil fertility of farmland in research area (Table III). The spatial distribution of soil fertility can be obtained by spatial analysis tools.

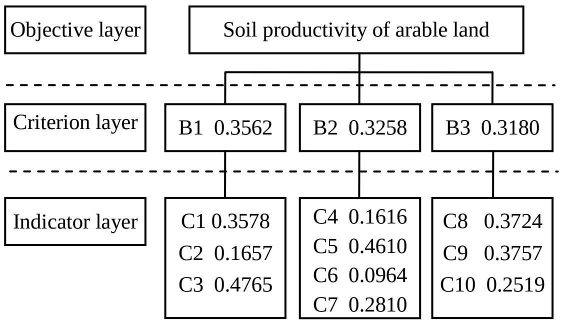

Figure 2. Hierarchy plot of soil productivity and assessing indicators

† B1: Site condition; B2: Physichemical property; B3: Profile configuration; C1: Annual precipitation; C2: Degree of slope; C3: Parent materials; C4: Soil pH; C5: Organic matters; C6: Soil bulk density; C7: Cultivating layer thickness; C8: Total N; C9: Available P; C10: Available K

TABLE III. THE CRITICAL VALUES OF DIFFERENT FERTILITY GRADES

Grade	*IFI*	Grade	*IFI*
Class 1	0.73-0.78	Class 4	0.62-0.65
Class 2	0.70-0.73	Class 5	0.52-0.62
Class 3	0.65-0.70		

III. RESULTS AND DISCUSSION

A. Soil nutrients

The assessing indicators of soil samples were summarized in Table IV. The soil pH ranged from 4.0 to 6.7, with the mean of 4.8, which indicated that the farmland soil was acidic. There was no significant difference of soil pH among the different farms in research area.

The concentration of soil organic matters was significantly varied in farmland soil of study area, which ranged from 2.8 to 56.5 g•kg^{-1}. The concentration of soil organic matters in Xinyang farm was the highest among the ten farms (Table IV), which was 28.3±11.8 mg•kg^{-1}, and Hongling farm was the lowest, which was 9.0±1.2 mg•kg^{-1}. The soil organic matters concentration in research area was 16.7 mg•kg^{-1}, and the farms which concentration of organic matters ranged from 10 to 20 g•kg^{-1} accounted for 92%.

The concentration of total N in soil of research area was 0.75 g•kg^{-1}, which indicated that the concentration of total N in Bayi farm areas were relatively lower (Table IV). The concentration of total N in different farms varied significantly. Concentration of total N in soil of Xinyang farm was the highest among the ten farms, which was 1.15 g•kg^{-1}.

The concentration of available P in soil of Bayi farm areas varied significantly, which ranged from 0.1 to 51.7 mg•kg^{-1}. The average concentration of available P was 9.4 mg•kg^{-1} and the variation coefficient was 104.3% (Table IV). Among the ten farms, the available P concentration in both Xilian and Bayi farms were higher than 10 mg•kg^{-1}, which were 18.7 and 13.6 mg•kg^{-1} respectively. The concentrations of available P in Xinying and Xiqing farms were relatively lower than other farms, which mainly distributed in the range from 3-10 mg•kg^{-1}.

TABLE IV. SELECTED NUTRIENT INDICATORS OF SOIL SAMPLES

Farm	Farmland Area	pH	Soil OM
	hm^2		g•kg^{-1}
Xinying	3721.5	4.7±0.3	28.3±11.8
Xiqing	5090.0	4.6±0.3	13.0±1.5
Xipei	3834.0	4.7±0.3	12.4±1.8
Xiliu	3084.3	4.8±0.4	25.8±6.3
Xilian	5548.5	4.8±0.4	13.9±3.5
Xihua	3674.0	4.8±0.3	12.6±2.2
Longshan	1503.4	4.8±0.3	13.8±3.0
Lanyang	2783.4	4.7±0.3	17.3±2.1
Hongling	1678.2	4.8±0.3	9.0±1.2
Bayi	7511.0	4.9±0.3	14.7±3.8
Total	38428.1	4.8±0.3	16.7±7.9

Farm	Total N	Available P	Available K
	g•kg^{-1}	mg•kg^{-1}	
Xinying	1.15±0.35	1.7±3.4	24.5±12.5
Xiqing	0.84±0.26	4.3±4.2	21.3±6.5
Xipei	0.93±0.24	9.2±7.5	20.4±6.2
Xiliu	0.88±0.19	7.2±7.4	13.2±3.4
Xilian	0.72±0.16	18.7±11.4	21.7±12.9
Xihua	0.62±0.11	8.4±9.9	20.0±6.7
Longshan	0.61±0.08	7.5±5.3	40.5±8.4
Lanyang	0.59±0.08	7.3±8.8	27.8±12.1
Hongling	0.57±0.08	8.5±5.7	48.4±12.5
Bayi	0.54±0.14	13.6±10.9	29.7±12.4
Total	0.75±0.28	9.4±9.8	26.0±13.5

The concentration of available K in soil of study area ranged from 5.0-110.0 mg•kg^{-1}, and the average concentration was 26.0 mg•kg^{-1}, which indicated that the concentration of available K was relatively lower in soil of research area. The concentrations of available K in different farms varied significantly (Table IV), the concentration of available K in Hongling farm was the highest, run up to 48.4 mg•kg^{-1}, while that of Xiliu farm was the lowest, which was only 13.2 mg•kg^{-1}.

B. Soil fertility

The soil fertility assessing results of farmland showed that the soil fertility was uneven distributed in study area (Table V). The farmland area of Class 3 and Class 4 accounted more than 60% of total assessing area. The area of Class 1 was only 2777.67 hm^2, which accounted for 7.23% of total assessing area. Farmland of Class 1 mainly distributed in Xilian, Xiliu and Bayi farms, which indicated that the soil fertility of these three farms was higher than other farms. The farmland of Class 2 was 6039 hm^2, accounting for 15.72% of total farmland of Bayi farm areas. The farmland of this Class mainly distributed in both Bayi and Xiliu farms, which were 1688.9 and 1836.9 hm^2.

TABLE V. DISTRIBUTION OF SOIL FERTILITY IN STUDY AREA

Grade	Farmland		Grade	Farmland	
	Area (hm^2)	Ratio (%)		Area (hm^2)	Ratio (%)
Class 1	2777.67	7.23	Class 4	8526.45	22.19
Class 2	6039.14	15.72	Class 5	5877.33	15.29
Class 3	15207.61	39.57	Total	38428.21	100.00

The total areas of Class 3 were 1207.61 hm^2, accounting for 39.57% of the total. The farmland of this Class was distributed in all farms, and the area of Bayi, Xipei, Xiqing and Xinying farms were more than 2000 hm^2.

The area of Class 4 was the second largest among the five Classes, which was 8526.45 hm^2. The farmland of this Class mainly distributed in Xiqing, Xihua and Xilian farms, which were 1721.1, 1578.2 and 1430.2 hm^2.and it indicated that the soil fertility of these four farms were relatively lower among the farms. The farmland area of Class 5 accounted for 15.29% of the total, which was 5877.33 hm^2. The area of Class 5 in both Hongling and Xiqing farms were more than 1000 hm^2.

Previous study indicated that the distribution of soil fertility mainly determined by topography and irrigations [3, 6]. However, this study result showed that the soil fertility mainly related with the distribution of topography (Figure 3). The farmland with higher soil fertility mainly distributed in both the east and west area, and the slope degrees of these areas were lower than 8°. And the concentrations of soil organic matters and nutrients in these areas were higher than those of other area.

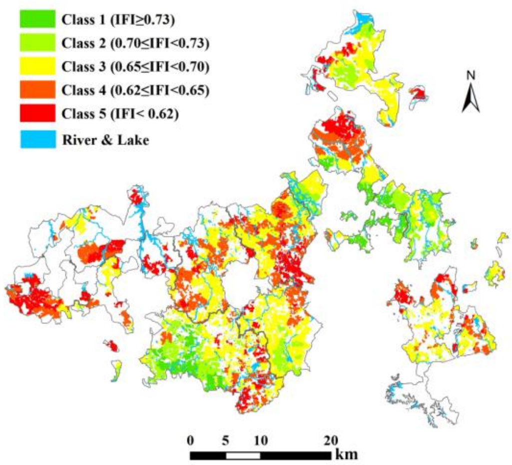

Figure 3. Spatial distirbuiton of soil fertility in study area

The lower fertility farmland maybe attributed to the excessively application of chemical fertilizers. The excessively application of chemical fertilizers can reduce the soil pH and decrease the concentration of soil organic matters. Therefore, in terms of the area with lower fertility levels, it will help to increase the soil organic matters concentration and soil pH by controlling fertilizations, such as adding apply organic fertilizer and applying the alkaline fertilizers.

IV. CONCLUSION

The concentrations of soil organic matters, total N, available P, and available K are in moderate levels but unevenly distributed in Bayi farm areas. The farmland soil is acidic, and the soil pH of study area is 4.8. The soil fertility of farmland is varied significantly in research area, and the soil fertility is moderate. The farmland area of Class 3 and Class 4 accounted more than 60% of the total.

The distribution of soil fertility of farmland is mainly determined by the distribution of topography. The higher fertility farmland mainly distributed in areas, which the degree of slope was lower than 8°. In terms of the area with lower fertility levels, some measures should be taken, such as increasing the volume of organic fertilizers and applying the alkaline fertilizers.

The spatial analysis tools of ArcGIS can be applied in soil fertility assessment. And this technique can present the spatial distribution of soil fertility in farmland; accordingly it is very significant to improve the soil fertility of farmland.

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