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Abstract: Studying the spatial distribution characters of rubber yield and soil nutrients and the rule of spatial variability are important for suitable fertilization strategy in rubber plantation. This paper selected Hongquan Branch, Guangba Branch and Gongai Branch of Guangba Farm in Hainan province as study area and total of 327 samples were selected in the rubber plantation. The spatial distribution characters of rubber yield and five soil nutrients, including organic matter (OM), total nitrogen (TN), available phosphorus (AP), available potassium (AK), exchangeable calcium (Ga), were studied using traditional analysis method and geo-statistics analysis method. The results showed that: (1) The average value of rubber yield was 3.55 kg/hm^2 with moderate spatial variability and the average values of OM, N, P, K and Ga were 11.65 g/kg, 0.07 %, 16.23 mg/kg, 49.65 mg/kg and 84.44 mg/kg, respectively. Soil OM, TN, AK and Ga had moderate spatial variability but AP had strong spatial variability. (2) Rubber yield and soil total nitrogen (N) nutrient had strong spatial dependence; soil OM, AP, AK and Ga had moderate spatial dependence. (3) Based on the previous reports of normal range of soil nutrients, soil OM and TN nutrient content were very low in the studied rubber plantation of Guangba Farm. Therefore, more nitrogen fertilizer should be applied in the rubber plantation in future.

Keywords: spatial distribution characters · rubber yield · soil nutrients · Guangba Farm

1 Introduction

Rubber plantation soil is an important resource of nutrient for rubber tree, the fertility condition is closely related to rubber growth and production. However, due to the influence of complex terrain, different cultivation methods and many factors in the process of soil-forming, the spatial distribution pattern of soil nutrient in rubber plantation is not homogeneous but highly heterogeneous, which made

the large spatial variability of rubber yield. Therefore, studying the spatial distribution characters of rubber yield and soil nutrients and the rule of spatial variability are important to formulate a suitable fertilization strategy in rubber plantation.

Recently, many researches about the spatial variability of soil nutrients of rubber plantation could be found in the literatures. Yang *et al.* [1] pointed out that both soil total potassium and available potassium had moderate spatial dependence in rubber plantation of Danzhou city. Yang [2] showed that soil available potassium (AK) and total potassium (TK) had strong spatial dependence; soil available nitrogen (AN), total nitrogen (TN), available phosphorus (AP), total phosphorus (TP), pH and organic matter (OM) had moderate spatial dependence in Lanyang Town rubber plantation. Qin *et al.* [3] showed that both soil total phosphorus and available phosphorus at the depth of 0-20cm and 20-40cm had moderate spatial dependence in rubber plantation of Qiongzhong County. Li *et al.* [4] found that OM, TN, available K (AK) and pH were at normal range but soil available P was below normal level in Dongfeng Farm of Yunnan province. In addition, all parameters of soil OM, TN, AK and pH had strong spatial dependence, indicting the spatial variability of these soil nutrients were mainly caused by structural factors, such as climate, terrain, agrotype and so on. Gao *et al.* [5] pointed out that soil available nitrogen, available phosphorus and available potassium had strong or moderate spatial dependence in rubber plantation of Ledong, Hainan. We can find from above researches that the spatial distribution characters of soil nutrients were different in different rubber plantations, even at the same site but at different time. So, the spatial distribution characters of soil nutrients should be studied for the specific research areas.

In addition, rubber yield is deeply affected by rubber plantation soil nutrients. Li *et al.* [6] pointed out the soil nutrients, such as nitrogen, potassium, phosphorus, can affect the rubber formation and latex flow through influencing the photosynthesis. So, the spatial heterogeneity of rubber plantation soil nutrients maybe lead to the spatial variability of rubber yield. Although many positive results of crop yield and soil nutrients have been reported in the literatures [7, 8, 9, 10], there has rarely studies about the spatial variability characters of rubber yield and its relationship with soil nutrients so far.

In this study, rubber yield and five soil nutrients were studied in Hongquan Branch, Guangba Branch, Gongai Branch of Guangba Farm. The objectives of this study were: (i) to assess the condition of rubber yield and soil fertility in the rubber plantation of Guangba Farm; and (ii) to understand the spatial variability characters of rubber yield and soil nutrients using Geo-statists method and the relationship between rubber yield and soil nutrients.

2 Materials and Methods

2.1 Study area

The study area is Hongquan Branch, Guangba Branch, Gongai Branch of Guangba Farm, which is located in the Dongfang city of Hainan province. This site has a mean annual rainfall of 1600 mm and a mean annual temperature of 24.2 °C. The terrain slopes gently with slopes of about 10 degrees and elevations of 120 m-160 m above the sea level. Rubber is one of the main economic forests planted in Guangba Farm with more than 3333 hm^2 in area. We conducted field surveys of rubber plantations and obtained rubber yield and corresponding soil nutrient parameters data in about 327 rubber stands. The location of Guangba Farm and field survey samples are shown in Fig. 1.

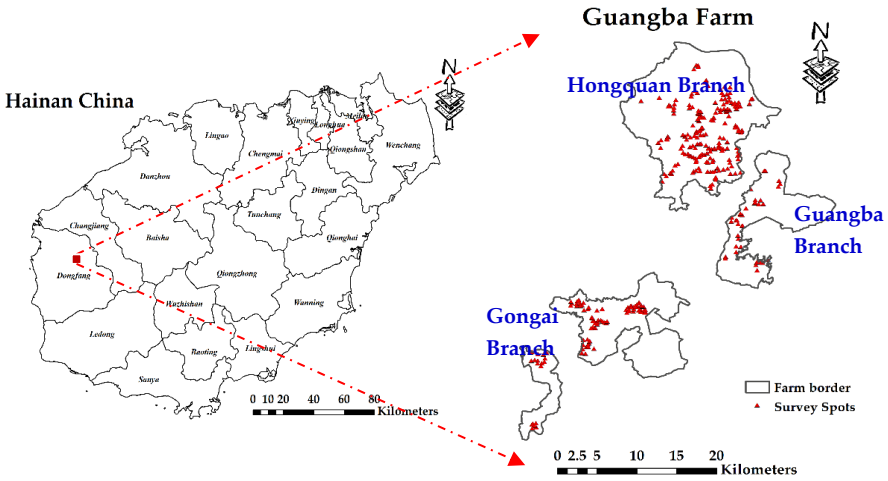

Fig.1. The location of study area and field survey samples

2.2 Data collection

In this study, a total of 327 rubber stands were randomly selected in the rubber plantation of Hongquan Branch, Guangba Branch, Gongai Branch of Guangba Farm in 2010. The detailed records of latex yield per time of each rubber stand were recorded, and the annual rubber yield at each rubber stand was calculated.

The corresponding 327 soil samples at the depth of 0-20 cm in the rubber plantation were collected in 2010. For each rubber stand, five representative soil-sampling sites were randomly selected within a 10 m radius near the center of site. Then they were mixed to form one composite sample representing this site. The location of each site was recorded by a DGPS receiver with accuracy of 0.2 m. Soil organic matter (OM) was calculated by using oil bath-$K_2Cr_2O_7$ titration method [11]. Soil total nitrogen (TN) was calculated by using semi-micro Kjeldahl method, soil available phosphorus (AP) was calculated by using Ammonium-hydrochloride method, soil available potassium (AK) was calculated by using NH_4OAc extraction- flame photometer method, and soil exchangeable calcium (Ga) was calculated by using 1 mol/L ammonium acetate exchange atomic absorption spectrophotometry [12].

2.3 Analyses method and software

The conventional statistics for raw experimental data was conducted using SPSS 22 software for Windows (SPSSInc., Chicago, IL, USA) with mean, maximum, minimum, standard deviation (SD), kurtosis, skewness and coefficient of variation (CV). Kurtosis and skewness values were used to test whether the raw data follow normal distribution. If the raw data did not follow normal distribution, 3δ Method [13], logarithmic or power transformations should be applied to meet the hypothesis of geo-statistical analysis. Coefficient of variation (CV) was identified as a basic parameter for spatial variability. If CV < 10 %, it means weak spatial variability; if 10 %< CV <100 %, it means moderate spatial variability; if CV >100 %, it means strong spatial variability.

The semi-variogram model was used to indicate spatial structure and the degree of spatial dependence of rubber yield and five soil nutrients. The semi-variogram model is described usually by five main parameters, i.e. nugget, partial sill, sill, range and Nugget/Sill [14]. Nugget means the spatial variation of variable was led by random factors and partial sill means the spatial variation was led by

structure factors such as soil texture, crop variety and etc. Sill is the sum of nugget and partial sill, which means the total spatial variation of variable. The range means the max distance between two locations with spatial dependence. The last but the most important parameter is the value of Nugget/Sill ratio, which can directly indicate the degree of spatial dependence and the reason led to spatial variation by random or structure factors. If the value of Nugget/Sill ratio < 25 %, it means strong spatial dependence and structure factors as dominant variation reason; if 25 % < Nugget/Sill ratio < 75 %, it means moderate spatial dependence; if Nugget/Sill ratio > 75 %, it means weak spatial dependence and random factors as dominant variation reason. The best fit theoretical semi-variogram model for different variables were simulated and the fitting accuracy were evaluated according to R^2 indicators. All above analysis were conducted using GS 10+ software.

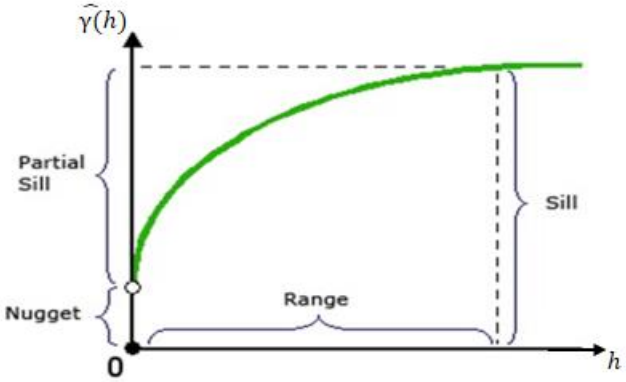

Fig.2. Parameters of semi-variogram model [14]

3 Results

3.1 Analysis rubber yield and soil nutrients

The basic statistical information of rubber yield and five kinds of soil nutrients, including soil organic matter (OM), total nitrogen (N), available phosphorus (P), available potassium (K) and exchangeable calcium (Ga), were shown in Table 1. For yield, OM, N, K and Ga, the coefficients of variation varied between 42.9 % and 86.5 %, which were greater than 10 % and less than 100 %, indicating all these parameters had moderate variability. However, the coefficient of variation for P reached up to 173.3 %, which meant the variability of P was strong.

Furthermore, because Geo-statistics analysis require all data studied should be normally distributed, all outliers should firstly be checked before the testing of data normal distribution using the 3δ Method. If the data are still non-normality distribution after correction outliers, data transform (log, square-root and etc.) should be used to ensure that the data obey the normal distribution. In this study, logarithm transition were used for the parameters of yield, P, K and Ga. Through the above-mentioned processing, the values of skewness and kurtosis of all data used in this study were very small as shown in Table 1, indicating that they were all normally distribution.

Table 1. The basic statistical information of rubber yield and five soil nutrients

	N	Min	Max	Mean	SD	CV (%)	Skewness	Kurtosis
Yield (kg/hm^2)	327	1.33	8.80	3.55	26.03	48.8%	0.34	-0.64
OM (g/kg)	327	0.50	29.10	11.65	5.72	49.1%	0.49	0.06
TN (%)	327	0.01	0.16	0.07	0.03	42.9%	0.81	0.46

AP (mg/kg)	327	1.10	165.70	16.23	28.12	173.3%	0.76	0.88
AK (mg/kg)	327	12.00	121.00	49.65	22.58	45.5%	-0.07	-0.14
Ga (mg/kg)	327	5.30	345.60	84.44	73.07	86.5%	-0.19	-0.45

Soil organic matter (OM); total nitrogen (TN); available phosphorus (AP); available potassium (AK); exchangeable calcium (Ga)

3.2 Analysis spatial distribution characters of rubber yield and soil nutrients

To understand the spatial structure and distribution of rubber yield within the farm is very importance to understand the difference of production capacity among different rubber stands and to make specific fertilizer application strategies according to different levels of yield capacity regions.

In this study, the best fit theoretical semi-variogram model and parameters for rubber yield and five soil nutrients were given in Table 2 and Fig. 3. The Exponential model was found to be the best fit model for rubber yield, and the range for yield was 3.34 km. Nugget: sill ratio values for rubber yield was 15.30 %, which was less than 25 %, indicating strong spatial dependence mainly resulted from structural factors such as rubber cultivar, terrain, climate and so on. The best fit model for the five soil nutrients was Exponential model. The values of $C_0/(C_0+C)$ for OM, AP, AK and Ga were in the range of 25 % - 75 %, but for N was less than 25 %, which indicated that soil OM, AP, AK and Ga had moderate spatial dependence and soil TN has strong spatial dependence. The R^2 for all parameters studied were in the range of 0.54 - 0.85, indicating that the selected models can preferably reflect the spatial distribution characters of these parameters.

Table 2. Best fit theoretical semi-variogram model and parameters for rubber yield and soil nutrients

	Model	Nugget	Sill	$C_0/(C_0+C)$	Range(km)	R^2
Yield (kg/hm^2)	Exponential	0.03	0.17	15.30%	3.34	0.54
OM (g/kg)	Exponential	24.100	50.2100	48.0%	71.47	0.73
TN (%)	Exponential	0.0001	0.0008	14.2%	3.01	0.71
AP (mg/kg)	Exponential	0.5610	1.5020	37.4%	219.74	0.85
AK (mg/kg)	Exponential	0.1229	0.3658	33.6%	252.47	0.60
Ga (mg/kg)	Exponential	0.3100	0.9060	34.2%	12.36	0.74

Soil organic matter (OM); total nitrogen (TN); available phosphorus (AP); available potassium (AK); exchangeable calcium (Ga)

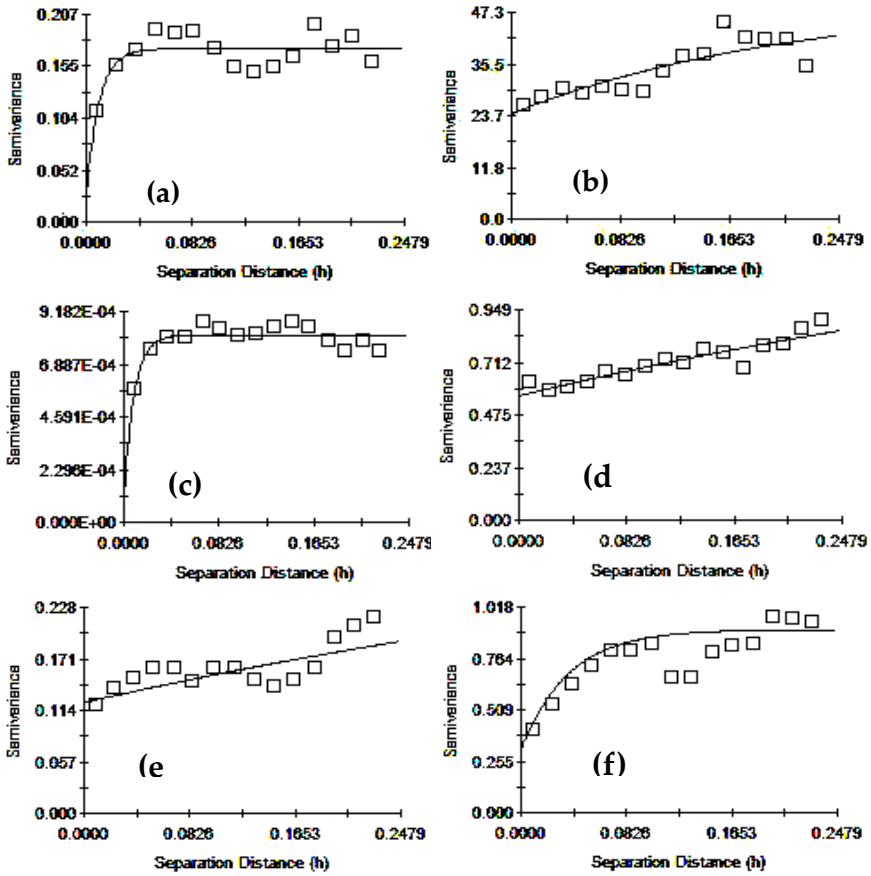

Fig.3. The semi-variograms of rubber yield and soil nutrients in the rubber plantation (a): rubber yield; (b): soil organic matter (OM); (c): total nitrogen (TN); (d): available phosphorus (AP); (e):available potassium (AK); (f) exchangeable calcium (Ga)

3.3 Analysis the potential balance of soil nutrients in the rubber plantation

Studying the balance of different soil nutrients in rubber plantation is important for making rational fertilizer application strategy, improving the effectiveness of fertilization and maintaining a high and stable rubber production. Based on previous studies of rubber plantation soil fertility condition by He *et al.* [15] and Wu *et al.* [16], the normal range for soil OM, TN, AP and AK nutrient were 20 g/kg - 25 g/kg, 0.08 % - 0.14 %, 5 mg/kg - 8 mg/kg, 40 mg/kg - 60 mg/kg, respectively and the threshold value of Ga was 25 mg/kg. The classification of different soil properties in the study area were shown in Table 3. The results showed that the levels of soil organic matter (OM) and total nitrogen (TN) nutrient in the studied rubber plantation were very low. For available phosphorus (AP) and available potassium (AK), only 26.30 % and 38.53 % of samples, respectively, were among in the normal range; in other words, the soil available phosphorus and available potassium nutrient were too less or too much in most areas of rubber plantation. The soil in the studied area was rich in exchangeable calcium (Ga) with 81.96 % samples greater than the threshold value (25 mg/kg).

Table 3. The classification of soil properties in rubber plantation of Guangba Farm

Soil properties		Low	Normal	High
organic matter	Grading standard	< 20 g/kg	20 - 25 g/kg	> 25 g/kg

(OM)	Number	302	18	7
	Percentage (%)	92.35 %	5.50 %	2.14 %
total nitrogen (TN)	Grading standard	< 0.08 %	0.08 - 0.14 %	> 0.14 %
	Number	223	97	7
	Percentage (%)	68.20 %	29.66 %	2.14 %
available phosphorus (AP)	Grading standard	< 5 mg/kg	5 - 8 mg/kg	> 8 mg/kg
	Number	90	86	151
	Percentage (%)	27.52 %	26.30 %	46.18 %
available potassium (AK)	Grading standard	< 40 mg/kg	40-60 mg/kg	> 60 mg/kg
	Number	122	126	79
	Percentage (%)	37.31 %	38.53 %	24.16 %
exchangeable calcium (Ga)	Grading standard	< 25 mg/kg	⩾ 25 mg/kg	/
	Number	59	268	/
	Percentage (%)	18.04 %	81.96 %	/

4 Discussion

In this study, rubber yield and soil nutrients shown obvious spatial dependence in the rubber plantation. The relationship between rubber yield and five soil nutrients were given in Table 4. Rubber yield were strongly related with soil available phosphorus (AP), available potassium (AK) and exchangeable calcium (Ga) at significance level of 0.01. But no relationships were found between yield and soil organic matter (OM), total nitrogen (TN), which was contradictive with the previous study by An *et al.* [17], it could mainly because the serious lack of soil OM and N. Luo *et al.* [18] pointed out that the leaf nutrient content was directly related to the nutrient condition of rubber tree and the latex yield, although soil was the source of rubber tree nutrient. The immobilization capability of soil and the absorption capacity of rubber tree may lead to less OM and TN content in soil but more in rubber tree. Therefore, comprehensive consideration of the soil nutrient and leaf nutrient is essential to know the factors affecting rubber yield.

Table 4. The relationship between rubber yield and soil nutrients

	OM	TN	AP	AK	Ga	Yield
OM (g/kg)	1	0.763**	0.048	0.260**	0.223**	0.004
TN (%)	0.763**	1	0.042	0.205**	0.197**	0.001
AP (mg/kg)	0.048	0.042	1	0.130*	0.030	-0.154**
AK (mg/kg)	0.260**	0.205**	0.130*	1	0.543**	-0.176**
Ga (mg/kg)	0.223**	0.197**	0.030	0.543**	1	-0.185**
Yield (kg/hm^2)	-0.210	0.001	-0.154**	-0.176**	-0.185**	1

Note：* Significant at the 0.05 level; ** Significant at the 0.01 level.

Soil organic matter (OM); total nitrogen (TN); available phosphorus (AP); available potassium (AK); exchangeable calcium (Ga)

5 Conclusion

Studying the rule of spatial variability of rubber yield and soil nutrients and their spatial distribution characters are important to formulate a suitable fertilization strategy in rubber plantation. The spatial distribution characters of rubber yield and five soil nutrients, including OM, TN, AP, AK, Ga were studied by using traditional analysis method and geo-statistics analysis method in this paper.

The average value of rubber yield was 3.55 kg/hm^2 with moderate variability. For the five soil nutrients, the average values of OM, TN, AP, AK and Ga were 11.65 g/kg, 0.07%, 16.23 mg/kg, 49.65 mg/kg and 84.44 mg/kg, respectively. Soil OM, TN, AK and Ga had moderate variability but P had strong variability. Through the analysis of semi-variograms, rubber yield and soil TN nutrient had strong spatial dependence; rubber yield and soil OM, AP, AK and Ga had moderate spatial dependence. Based on the previous studies of standard range of soil nutrients, OM and TN nutrient were very low in the studied rubber plantation of Guangba Farm. Therefore, more nitrogen fertilizer should be applied in the rubber plantation in Guangba Farm in future.

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