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佛山地区存留自然林和存留人工林的土壤无机磷组分

侯恩庆[1,2,3], CHEN Cheng-rong[2], 黎建力[4], 左伟东[4], 王瑜[1,3], 汪学金[1,3], 温达志[1*]

(1. 中国科学院华南植物园，广州 510650；2. *Environmental Futures Centre, Griffith School of Environment, Griffith University*, Brisbane 4111, Australia；3. 中国科学院研究生院，北京 100049；4. 佛山市南海区农林技术推广中心，广东 佛山 528222)

摘要：为探讨热带亚热带森林，尤其城市及其周边地区残存森林土壤磷的有效性，对佛山地区 14 个残存林(7 个自然林和 7 个人工林)的 0~3 cm 和 3~23 cm 矿质土壤的 P 有效性进行研究。结果表明，铁结合态无机 P 和还原剂可溶解无机 P 是土壤无机 P 的主要组分。在 0~3 cm 矿质层中，自然林土壤铝结合态无机 P、Bray 1 提取无机 P 和总无机 P 含量显著高于人工林；而在 3~23 cm 矿质土层中，自然林土壤钙结合态无机 P 含量显著高于人工林。其它土壤营养指标在自然林和人工林间差异不显著。相关分析结果表明，土壤有机质含量与钙结合态无机 P 除外的其它无机 P 组分含量均成显著正相关。聚类分析结果表明 14 个残存林土壤 P 有效性可分成 3 组，整体上人工林土壤 P 有效性比自然林低。这有助于认识城市化影响下城市及其周边地区残存森林土壤营养状况及加强养分管理。

关键词：无机磷组分；残存林；磷有效性；佛山地区

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Soil Inorganic Phosphorus Fractions of Remnant Native and Plantation Forests in Foshan Region

HOU En-qing[1,2,3], CHEN Cheng-rong[2], LI Jian-li[4], ZUO Wei-dong[4], WANG Yu[1,3], WANG Xue-jing[1,3], WEN Da-zhi[1*]

(1. *South China Botanical Garden, Chinese Academy of Sciences*, Guangzhou 510650, China; 2. *Environmental Futures Centre, Griffith School of Environment, Griffith University*, Brisbane 4111, Australia; 3. *Graduate University of Chinese Academy of Sciences*, Beijing 100049, China; 4. *Agriculture and Forestry Technology Extension Centre of Nanhai District in Foshan*, Foshan 528222, China)

Abstract: Soil phosphorous (P) availability is always thought to be a limiting factor for ecosystem primary productivity in the highly weathered tropical and subtropical areas, but our knowledge about soil P availability in tropical and subtropical forests is still poor, particularly in remnant native forests and frequently disturbed plantation forests in the urban and suburban areas. The soils at 0–3 cm and 3–23 cm mineral depths from 14 forest patches in Foshan region (seven native forest patches and seven plantation forest patches) were collected, and pH in water and concentrations of organic carbon (C), total nitrogen (N), total P, Bray-1 Pi and sequential extractable inorganic P fractions to estimate soil P availability were determined. The results showed that Fe-Pi and reductant soluble inorganic P were major inorganic P fractions at the study forest patches. Most of the selected soil nutrient

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HOU En-qing (1986~). E-mail: houeq@scib.ac.cn

* Corresponding author. E-mail: dzwen@scib.ac.cn

measures did not differ significantly between forest types in both soil layers. The concentrations of Al-Pi, Bray 1-Pi and total Pi in the 0–3 cm mineral soil layer and Ca-Pi in the 3–23 cm mineral soil layer were significantly lower at the plantation forest patches than those at native forest patches. Concentrations of organic C, total N, total P and all P fractions were significantly higher in 0–3 cm mineral soil layer than those in the 3–23 cm mineral soil layer for both forest types. Correlation analysis indicated that soil organic matter concentration was significantly and positively correlated with soil concentrations of all inorganic P fractions except Ca-Pi. Fourteen selected forest patches could be divided into three groups according soil P availability by Cluster analysis. Generally, the plantation forest patches were lower in soil P availability compared to native forest patches. These could help us for understanding the soil nutrient status and strengthen nutrient management at remnant forest patches in the urban and suburban areas.

Key words: Inorganic phosphorus fractions; Remnant forest; Phosphorus availability; Foshan region

Phosphorus (P) is considered as one of the most common nutritional constraints for forest ecosystem productivity, especially in the strongly weathered tropical and subtropical regions[1–3]. In subtropical China, soil P availability is generally low[4], as soils in this region are developed on the strongly weathered parent materials[5–6]. Moreover, enhanced soil acidification by continous acid deposition may further reduce the soil P availability by its precipitation with free iron (Fe) and aluminum (Al)[3,7]. Phosphorus has been thought to be one of the major limiting nutrients for forest growth in this region according to previous studies which showed high ratio of nitrogen (N) to P in leaf or low total P and available P contents in soils[8–9]. Therefore, both scientists and forest managers have become increasingly concerned about the potential effects of the P limitation on the regional forest growth in recent years[8–10].

Soil P availability exists as a continuum, and different fractions of soil P are inter-changeable and reach an equilibrium state eventually[11–12]. Different fractions of P might be available to plants at different time scales[11]. Separating total P into fractions of different solubility was found to be helpful to improve our understanding about the P supply in forest soils both in short and long terms[11,13]. The inorganic P sequential extraction of Chang and Jackson (1957) and its modified methods have been widely used to investigate the forms of inorganic P and soil P availability in the past decades[13–15]. Inorganic P was generally divided into four fractions by these methods, including P fractions that associated with soluble Al, Fe and calcium (Ca), and P fraction that occluded by free oxide coatings[14,16]. These methods are considered to be useful to investigate the form and nature of soil P and its availability[10,13], and to provide useful information for indentifying status of soil weathering[5,17]. Studies on soils across long chronosequence found that Ca-associated P fraction was changing into Al-associated P and Fe-associated P fractions with increasing soil development (i.e. increasing weathering and leaching)[5,17].

Foshan region has experienced a rapid economic growth with associated expansion of urban areas during the last three decades[18]. More than 80% of the population in this area now lives in urban areas[19]. Rapid urbanization has resulted in a loss of more than 30% of the forest areas during the 1988–2003, which were mainly transformed to farmland, dike-pond or built-up areas[18]. In the urban and suburban areas, only small catchments of remnant native forests nearby villages or graveyards are left, which benefit from the geomantic culture of China[20–21]. Some forests in hill lands are also left, as these lands are not suitable for farming or construction. These two types of forest sites are currently major remnant forest sites in urban and suburban areas in Foshan region. Their important roles in adjusting urban climate, fixing carbon (C) and preserving biological diversity were gradually recognized by local government, forest managers, and scientists[21–22]. However, little is known about the availability of soil nutrients in these forest sites, though soil nutrients of these forest sites were thought to be different, as different tree species, community composition, stand ages and forest managements were observed or documented between or within these two types of forest sites[21,23–24].

In this study, we collected soils at 0–3 cm and 3–23 cm mineral depths from 14 forest patches (including seven native forest patches and seven plantation forest patches) in the urban and suburban areas in Foshan region, and analyzed the concentrations of organic C, total N and total P and inorganic P fractions, to investigate the soil P availability at the remnant forest patches and study the impacts of reforestation on soil P availability at the plantation forest patches in the urban and suburban areas in Foshan region. We hypothesized that soil P availability was lower at the plantation forest patches than that at the native forest patches.

1 Materials and methods

1.1 Site descriptions

This study was carried out in Foshan region (22º38′–23º34′ N, 112º22′–113º23′ E), Guangdong Province, China. This district is characterized by a typical subtropical monsoon climate, with mean annual precipitation of about 1600 mm, of which nearly 80% falls in the hot-humid season (from April to September) and 20% in the cool-dry season (from October to March)[18,25]. The mean annual temperature is about 22℃, with the coldest and warmest monthly mean temperature of 13℃ in January and 27℃ in July, respectively[18,25]. The soil is lateritic red earth developed from granite[25].

Native forest patches are woodlands that are older than 60 years and located nearby villages or graveyards and maintained by local residents for the geomantic culture of China (called fengshui woods)[20–21]. These culturally protected forests are the only type of the forests that is similar to the zonal vegetation in the urban and suburban areas in Foshan region[21]. Plantation forest patches are woodlands that experienced two rotations of reforestation during the last 60 years, and remained due to their unsuitability for farming and construction. Before the first rotation of reforestation, the vegetation at the plantation forest patches is believed to be the same as that at the native forest patches. The first rotation was reforested with pine and/or eucalyptus species later after the harvest of native forests during the 1970s–1980s[23,26–27]. The second rotation was reforested with saplings of native broadleaf tree species by imitating the tree species and community composition of the native forest patches around the year 2000[21].

1.2 Soil sampling and chemical analysis

For both native and plantation forests, seven patches were randomly selected in Foshan region. Basic information of the 14 selected forest patches are shown in Table 1. Soils were sampled during Dec. 2008–Jan. 2009. At each forest patch, four sample areas were randomly selected with a distance of at least 50 m between each other. In each sample area, after forest floor materials were removed, soils at 0–3 cm and 3–23 cm mineral depths were sampled from down to up after a soil profile was excavated. We divided the soils into 0–3 cm and 3–23 cm depths because most of the excavated soil profiles with an apparent color change at the mineral depths of about 3 cm. Four soils at the same depth of each forest patch were equally mixed as one composite sample. And finally a total of 28 soil sample (2 forest types × 7 patches × 2 soil depths) were prepared for laboratory analysis. Soils were air dried and then sieved through 10 mesh sieve to remove roots, gravel and stones. Subsamples of the sieved soils were ground to pass 100 mesh sieve for the determination of concentrations of organic C, total N and total P. All samples were stored in sealed plastic containers before analysis.

Soil pH was measured using a soil∶water ratio of 1∶2.5. Organic C concentration was measured by dichromate oxidation methods[28]. Total N concentration was determined with the semimicro-Kjeldahl digestion followed by the detection of ammonium[28]. Total P was analyzed by the molydate

Table 1 Site information of the 14 selected forest patches in Foshan region

Forest type	Patches	Topography	Elevation (m)	Area (hm^2)	Major tree species
Native	Lunyong	Slope	16–65	9.5	*Schima superba, Indocalamus tessellates, Alpinia chinensis*
	Shukeng		60–87	5.9	*Machilus chinesis, Lasianthus chinensis, Indocalamus tessellates*
	Linyue		10–32	20.8	*Syzygium hancei, Symplocos lancifolia, Desmos chinensis*
	Shanbu		10–27	9.0	*Phoebe namu, Ardisia hanceana, Ixora chinensis*
	Kengmei	Flat	5	4.6	*Schefflera octophylla, Desmos chinensis, Alocasia macrorhiza*
	Yangao		15	3.0	*Syzygium hancei, Bambusa stenostachya, Ardisia hanceana*
	Yuantou		5	2.9	*Helicia cochinchinensis, Desmos chinensis, Ardisia hanceana*
Plantation	Xialiang	Slope	15–36	10.7	*Cinnamomum camphora, Castanopsis hystrix, Liquidambar formosana*
	Zhanqigang		16–108	83.7	*Cinnamomum camphora, Liquidambar formosana, C. burmannii*
	Sanguigang		40–69	42.2	*Ficus altissima, Polyspora axillaris, Bombax malabaricum*
	Zhongxingang		6–73	32.8	*Ficus altissima, Cinnamomum camphora, Schima superba*
	Longtou		10–26	5.6	*Cinnamomum camphora, Albizia falcataria, Delonix regia*
	Xian		5–33	38.7	*Schima superba, Liquidambar formosana, Ficus microcarpa*
	Xinjing		30–65	104.0	*Ficus altissima, F. microcarpa, Bischofia javanica*

blue method after digested with $HF/HClO_4$[28]. Bray 1-Pi was extracted with 0.03 mol L^{-1} NH_4F – 0.025 mol L^{-1} HCl and analyzed by the molybdate blue method[29–30]. Inorganic P fractions were sequentially extracted with 1 mol L^{-1} NH_4Cl (represents the soluble and loosely bound inorganic P, SLPi in abbreviation), 0.5 mol L^{-1} NH_4F (Al associated inorganic P, Al-Pi), 0.1 mol L^{-1} NaOH (Fe associated with inorganic P, Fe-Pi), 0.3 mol L^{-1} $Na_3C_3H_6O_7^{-1}$ mol L^{-1} $NaHCO_3$-$Na_2S_2O_4$ (reductant soluble inorganic P, RSPi) and 0.25 mol L^{-1} H_2SO_4 (Ca associated inorganic P, Ca-Pi), following the procedures of Kovar and Pierzynski[16]. Since the color of the extracts of Al-Pi, Fe-Pi and RSPi were dark and could affect the colorimetric analysis, activated carbon was used to eliminate the color of these extracts before the colorimetric analysis[30]. Total inorganic P (total Pi in abbreviation) concentration was calculated as the sum of concentrations of all inorganic P fractions (SLPi, Al-Pi, Fe-Pi, RSPi and Ca-Pi). Total organic P (total Po) concentration was calculated as the difference between the total P concentration and the total Pi concentration.

1.3 Data analysis

Independent-samples *t* test was used to compare the differences in soil properties between the native and plantation forests for each soil layer. Paired-samples *t* test was used to compare the differences in soil properties between the 0–3 cm and 3–23 cm mineral soil layers for each forest type. Pearson correlation was used to analysis the relationships between soil properties for all soils. Hierarchical cluster analysis using the Furthest neighbor method and Z-scores transformation was carried out to classify the soil P availability of 14 selected forest patches. All these analyses were carried out using the SPSS version 16.0 for Windows. The ratios of C：N, C：P and N：P were all on a mass basis.

2 Results and discussion

2.1 Overall soil characteristics

Soil pH values (3.8–4.3) were low at all studied forest patches (Table 2), indicating a general strong soil acidity in the forested areas in Foshan region. Soil total P concentration and C：P and N：P ratios are indicators of soil P availability frequently used in previous studies[4,31]. In this study, mean total P concentration of all soils (338 mg kg^{-1}; Table 2) was lower than the mean value of soil total P concentration in tropical and subtropical China (589 mg kg^{-1})[31], and mean C：P and N：P ratios (80.7 and 7.0, respectively; Table 2) were both more than twice of those in tropical and subtropical China (30.2 and 2.9, respectively)[31], indicating a relative low supply of soil P to vegetation growth in the forested areas in Foshan region compared to many other tropical and subtropical areas of China.

Table 2 Statistics of soil properties of forest patches

Soil properties	Mean	SE	Range
pH	4.0	0.0	3.8–4.3
Organic C (g kg^{-1})	26.2	3.0	6.4–51.7
Total N (g kg^{-1})	2.4	0.4	0.5–7.9
Total P (mg kg^{-1})	338.1	31.0	107.0–754.0
C : N	12.9	1.1	6.5–35.7
C : P	80.7	8.2	23.1–188.9
N : P	7.0	0.8	1.5–19.8
Bray 1-Pi (mg kg^{-1})	9.0	2.2	0.8–56.0
SLPi (mg kg^{-1})	0.7	0.2	0–3.1
Al-Pi (mg kg^{-1})	26.3	6.2	1.4–151.8
Fe-Pi (mg kg^{-1})	47.2	7.4	9.6–145.7
RSPi (mg kg^{-1})	67.2	6.8	18.2–165.7
Ca-Pi (mg kg^{-1})	6.0	0.8	0.8–16.8
Total Pi (mg kg^{-1})	147.4	17.3	31.9–399.6
Total Po (mg kg^{-1})	190.7	19.9	20.1–475.7

The composition of inorganic P fraction has been extensively discussed during the past decades, and was thought to be largely dependent on the parent material, soil weathering and soil type[5,32–33]. In this study, RSPi and Fe-Pi were the largest inorganic P fractions, accounting for 21.1%–80.2% (mean 50.4%) and 13.7%–52.7% (mean 30.1%) of the total Pi, respectively. This result is consistent with two other studies carried out on forest soils in south China[13,34]. The consistent composition pattern may be because of the highly weathered and Al- and Fe-rich characteristics of many forest soils in south China[5–6], as Ca-P might have been gradually changed into Al-Pi and Fe-Pi with increasing degrees of weathering and leaching[5,33].

2.2 Comparison between forest patch types and soil layers

None of the basic soil properties differed significantly between the forest patch types in both soil layers, though concentrations of organic C, total N and total P were all tended to be lower at the plantation forest patches than at the native forest patches in both soil layers (Table 3). Concentrations of most of the P fractions also did not differ significantly between two types of forest patches in both soil layers (Table 4). The exceptions were the concentrations of Bray 1-Pi, Al-Pi and total Pi in 0–3 cm mineral soil layer and Ca-Pi concentration in 3–23 cm mineral soil layer that were all significantly lower at the plantation forest patches than at the native forest patches (Table 4).

Table 3 Comparison of basic soil properties between forest types and soil layers

Soil depth (cm)	Forest type	pH	Organic C (g kg^{-1})	Total N (g kg^{-1})	Total P (mg kg^{-1})	C : N	C : P	N : P
0–3	Native	3.9±0.0aB	43.0±3.1aA	4.5±0.8aA	487.6±77.6aA	11.0±1.5aA	97.6±11.6aA	9.3±0.9aA
	Plantation	3.9±0.1aB	38.6±2.4aA	3.2±0.6aA	311.7±34.7aA	15.1±3.6aA	130.3±12.9aA	10.6±2.0aA
3–23	Native	4.0±0.1aA	12.9±0.7aB	1.2±0.2aB	317.0±49.9aB	11.9±1.7aA	44.7±4.7aB	4.1±0.5aB
	Plantation	4.2±0.0aA	10.3±1.0aB	0.8±0.1aB	236.3±43.9aB	13.6±1.5aA	50.2±7.3aB	4.1±0.9aB

n =7. Data followed different small and capital letters indicate significant difference at 0.05 level between forest types and soil layers, respectively.

In general, these results suggested that reforestation might not significantly reduce soil nutrient concentrations or the reductions might have been largely recovered during the past years of recovery. Since wood harvest, burns of harvest residues and thereafter reforestation with saplings are all likely to reduce soil nutrient concentrations at the plantation forest patches[35–37], the insignificant difference of soil nutrient concentrations between forest patch types is some surprising. We proposed that widespread high atmospheric N deposition in the Pearl River Delta area where Foshan region located might have accelerated the recovery rate of soil organic C and total N concentrations by applying abundant N resource for vegetation growth[38–39]. Large variations of within forest patch type of the selected properties may also contribute to the general insignificant differences observed in this study, since the study forest patches are widespread in Foshan region.

Table 4 Concentration ($mg\ kg^{-1}$) of soil fractions in forest types and soil layers

Soil depth (cm)	Forest type	Bray 1-Pi	SLPi	Al-Pi	Fe-Pi	RSPi	Ca-Pi	Total Pi	Total Po
0–3	Native	21.7±6.2aA	1. 6±0.4aA	65±17aA	79±20aA	98±10aA	7.5±1.9aA	251±39aA	237±49aA
	Plantation	6.2±0.8bA	1.1±0.2aA	22±4bA	39±10aA	71±18aA	5.1±1.1aA	138±23bA	174±40aA
3–23	Native	6.3±2.8aB	0.2±0.1aB	14±5aB	50±13aA	53±8aB	8.1±1.6aA	126±22aB	191±32aA
	Plantation	1.9±0.4aB	0.1±0.0aB	4±1aB	21±6aB	46±8aA	3.3±0.9bA	75±12aB	162±39aA

n=7. Data followed different small and capital letters indicate significant difference at 0.05 level between forest types and soil layers, respectively.

Although reforestation might not significantly affect the total P concentrations of both 0–3 cm and 3–23 cm mineral soils at the study forest patches, it probably have significantly reduced the concentrations of available P fractions of the 0–3 cm mineral soil, and the impact was probably still significant after about 9 years of recovery. As Bray 1-Pi is always taken as the available P fraction for plant growth in acid soil[29,40–41], and is frequently found to be related to the P uptake by plant growth[42–43]. Soil Al-Pi concentration is also usually found to be available to plants[15,44]. Soil Bray 1-Pi and Al-Pi concentrations at the plantation forest patches were both only about 30% of those at the native forest patches in both soil layers (Table 4). The slow recovery of concentrations of available P fractions may be because of the low atmospheric P deposition and low soil P weathering rate in the study area[6,45]. This result is coincident with our previous study that found soil concentration of mineral nutrient with low atmospheric input (potassium) was significantly lower at the plantation forest patches than at the native forest patches, while soil concentration of mineral nutrient with high atmospheric input (calcium) did not differ significantly between two types of forest patches[46]. Both of these two studies suggested the significant role of atmospheric deposition in determining the recovery rates of soil mineral nutrients at the plantation forest patches of the study area, which need further study to verify in future.

Most of nutrient concentrations were significantly higher in the 0–3 cm mineral soil layer than in the 3–23 cm mineral soil layer for both types of forest patches (Tables 3 and 4). This result is likely to reflect the uplift of nutrients by plant cycling, especially for the strongly cycled nutrients[47]. Differences in SLPi and Al-Pi concentrations between soil layers were larger than the differences in Fe-Pi and RSP concentrations between soil layers, indicating a more strongly cycling of soil SLPi and Al-Pi fractions than soil Fe-Pi and RSPi fractions by vegetation growth.

2.3 Relationships between soil properties

Soil pH was significantly and negatively correlated with the concentrations of Bray 1-Pi, SLPi, Al-Pi, RSPi and total Pi (Table 5). The negative relationships might be because of the increasing activation of Al and Fe and thus releasing of inorganic P by increasing soil acidity (decreasing soil pH), since Al^{n+} and Fe^{n+} are likely to be the major cations buffering soil acidity at the study forest patches as suggested by the soil pH (3.8–4.3)[48]. Soil organic C concentration was significantly and positively correlated with soil concentrations of all inorganic P fractions except Ca-Pi (Table 5), indicating a significant role of soil organic matter in maintaining soil P availability at the study forest patches. Positive relationships between soil organic C (or organic matter) concentration and soil inorganic P concentrations were also reported by some other studies[49–50]. The relationship may be because of the sorption of inorganic P by organic matter in the soil[49].

SLPi is always believed to be one of the most available P fractions for plant growth[14,16,51], and

Bray 1-Pi was proposed to be one of most effective P fractions in predicting responsiveness and fertilizer requirement of plants in acid soils[30,42–43]. Other P fractions which are highly correlated with these two fractions of P may be considered to be potentially available to plants[11]. In this study, both Al-P and Fe-P fractions were highly correlated with the Bray 1-Pi and SLPi fractions (r = 0.58–0.96, P < 0.05; Table 5), indicating the potential availability of Al-Pi and Fe-Pi fractions to plants.

Table 5 Correlations between soil properties

Property	pH	OC	TN	TP	C：N	C：P	N：P	Bray 1-Pi	SLPi	Al-Pi	Fe-Pi	RSPi	Ca-Pi	Total Pi
OC	**–0.52**													
TN	–0.30	**0.86**												
TP	–0.14	**0.58**	**0.69**											
C：N	–0.05	–0.06	**–0.45**	–0.29										
C：P	–0.31	**0.69**	**0.74**	0.08	**–0.40**									
N：P	**–0.49**	**0.67**	**0.39**	–0.16	0.27	**0.74**								
Bray 1-Pi	**–0.49**	**0.56**	**0.49**	**0.63**	–0.06	0.11	0.07							
SLPi	**–0.51**	**0.80**	**0.60**	**0.65**	0.03	0.28	0.33	**0.79**						
Al-Pi	**–0.44**	**0.64**	**0.58**	**0.65**	–0.12	0.23	0.15	**0.96**	**0.82**					
Fe-Pi	–0.36	**0.51**	**0.56**	**0.76**	–0.10	0.07	–0.01	**0.75**	**0.58**	**0.73**				
RSPi	**–0.38**	**0.49**	**0.43**	**0.55**	–0.12	0.13	0.11	**0.38**	**0.54**	0.37	**0.45**			
Ca-Pi	0.01	0.22	**0.39**	**0.71**	–0.36	–0.09	–0.32	0.22	0.24	0.25	**0.60**	**0.47**		
Total Pi	**–0.46**	**0.66**	**0.64**	**0.81**	–0.15	0.16	0.08	**0.83**	**0.77**	**0.83**	**0.90**	**0.74**	**0.58**	
Total Po	0.18	0.34	**0.52**	**0.86**	–0.32	–0.01	–0.32	0.26	0.34	0.29	**0.40**	0.21	**0.61**	**0.38**

Data in bold indicate significant correlations at 0.05 level.

2.4 Different P availability at different forest sites

As indicated by results in this study and some previous studies, the Bray 1-Pi, SLPi, Al-Pi and Fe-Pi are all likely to be available to plants[14–16,42–43]. We included concentrations of these four inorganic P fractions of the 3–23 cm mineral soils in a cluster analysis to group the 14 selected forest patches with respect to the different P availability. Three major groups of forest patches were identified from the dendrogram derived from cluster analysis. The results are shown as following (Fig. 1 and Table 6):

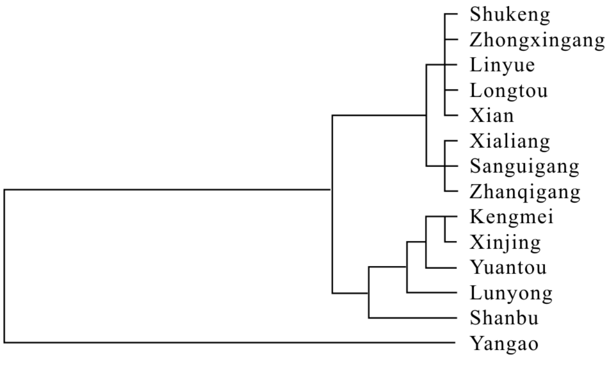

Fig. 1 Hierarchical cluster dendrogram of P availability in 3–23 cm mineral soils of 14 selected forest patches.

Table 6 Statistics of inorganic P concentrations (mg kg^{-1}) of three 3 groups

Variance	Group A*		Group B**		Group C***
	Mean	SD	Mean	SD	
Bray 1-Pi	1.7	0.8	4.5	3.6	21.3
NH_4Cl-P	0.1	0.1	0.2	0.1	0.4
Al-P	3.0	1.2	12.4	2.0	42.3
Fe-P	14.3	5.5	55.4	15.2	104.8

* include Shukeng, Zhongxingang, Longtou, Xian, Linyue, Xialiang, Sanguigang and Zhanqigang；** include Kengmei, Xinjing, Yuantou, Shanbu and Lunyong; *** include Yangao.

Low P availability: Shukeng, Zhongxingang, Longtou, Xian, Linyue, Xialiang, Sanguigang and Zhanqigang;

Middle P availability: Kengmei, Xinjing, Yuantou, Shanbu and Lunyong;

High P availability: Yangao.

All plantation forest patches except for the Xinjing forest patch were in the low soil P availability group, reflecting the generally low soil P availability at the plantation forest patches. In contrast, soil P availability at the native forest patches varied more greatly, with two forest patches in the low P availability group, four forest patches in the middle P availability group and one forest patch in the high P availability group.

3 Conclusions

Results in this study showed that soil P availability was relative low at the remnant forest patches in Foshan region, compared to many other tropical and subtropical areas of China. Fe-Pi and RSPi were major inorganic P fractions at the study forest patches. Most of the selected soil nutrient measures did not differ significantly between two types of forest patches in both soil layers, suggesting a possible large recovery of surface soil nutrients or insignificant impacts of reforestation on surface soil nutrients at the plantation forest patches. However, concentrations of Al-Pi, Bray 1-Pi and total Pi in 0–3 cm mineral soil layer were significantly lower at the plantation forest patches compared to the native forest patches, indicating a slow recovery of soil available P at the plantation forest patches, which might be related to the low atmospheric P deposition characteristic. Concentrations of organic C, total N, total P and all P fractions were significantly higher in 0–3 cm mineral soil layer than those in 3–23 cm mineral soil layer for both types of forest patches, reflecting a significant uplift of soil nutrients by plant cycling at both types of forest patches. Correlation analysis suggested that soil organic matter probably played a significant role in maintaining soil P availability at the study forest patches, and Al-Pi and Fe-Pi fractions were potential available P fractions for plant growth. Fourteen selected forest patches were divided into three groups with different soil P availability by cluster analysis. Generally, the plantation forest patches were lower in soil P availability compared to native forest patches. Results in this study provided a scientific basis for the soil nutrient managements at remnant forest patches in the urban and suburban areas in Foshan region.

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