A 10-Year Monitoring of Soil Properties Dynamics and Soil Fertility Evaluation in Chinese Hickory Plantation Regions of Southeastern China

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A 10-year monitoring of soil properties dynamics and soil fertility evaluation in Chinese hickory plantation regions of southeastern China

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Abstract

Long-term monitoring shows intensive management can significantly change soil properties and cause soil degradation. Knowledge related to the spatio-temporal variation of soil properties and their influencing factors are important for nutrient management of economic forest plantation. Here, we conducted an intensive field investigation in Chinese hickory plantation to clarify the spatial and temporal variation of soil properties and its influencing factors, and to evaluate the change of soil fertility. The results showed that the soil pH and soil organic carbon (SOC) significantly increased from 2008 to 2018, while available N significantly decreased from 2008 to 2018. The semi-variance revealed that except available P, the spatial dependencies of soil properties increased from 2008 to 2018. An increasing south-north gradient was found for soil available N, available P, available K and SOC and a decreasing south-north gradient was found for soil pH. One-way ANOVA analysis showed that the change of soil properties from 2008 to 2018 was mainly influenced by anthropogenic factors. The average soil fertility in the whole area was at a medium level from 2008 to 2018. These change of soil properties can provide a reference basis for monitoring the effects of intensive management on soil environment.

Keywords: Chinese hickory; Spatio-temporal variation; Soil properties; Soil fertility; Anthropogenic factors;

Introduction

Soil plays an important role in ecosystem processes that control nutrient cycling. Long-term monitoring of soil properties contributes to sustainable agricultural development, improving food quality and safety, as well as to maintaining or improving soil fertility levels and avoiding soil degradation[1]. Numerous studies[2-4] have been carried out in terrestrial ecosystems to study the factors affecting soil properties. These factors can be categorised into external factors, such as altitude, climate, topography, land use and management, internal factors, such as parent material, porosity, microbe[5-12]. Since 1980, with the implementation of China's reform and opening-up policy, Chinese agriculture has changed with mechanized farming and chemical fertilization increasing[13]. And long-term intensive agricultural management significantly changed soil pH, nutrient status, microbial biomass and community composition[14-17]. In addition, over-or inappropriate fertilization has caused various environmental problems, such as air pollution, water pollution, soil erosion, soil acidification and biodiversity loss[18-20]. This not only causes economic losses, but also has a negative impact on environmental safety and human health[21-23].

China, the largest developing country in the world, has experienced a rapid shift from natural vegetation lands into economic forests since the 1960s, due to an expanding human population. Economic forests are widely distributed in China, with a total area of 20.57 million ha, accounting for 9% of the national forest area[24]. Thus, economic forests are critical to promoting economic development and participating in C balance at regional and national scales. However, such large-scale land use change would markedly alter soil physio-chemical and biological properties[25]. For example, inappropriate management practices (pure forest management, deep ploughing and pruning) have led to a reduction of soil microorganisms and the imbalance of soil nutrients[26-29]. Therefore, understanding the effect of economic forest management practices on soil properties is much of importance to achieve sustainable use of forest soil.

Chinese hickory is a unique edible nut and woody oil species that distributed in the Tianmu mountain in Zhejiang province of southeastern China. Because of its unique taste and high nutritional value, the area of Chinese hickory has reached 93,300 ha with a total yield of 31,500 t in 2018[30,31]. For the purpose of improving the yield of Chinese hickory, farmers have adopted intensive agricultural management with extensive application of chemical fertilizer. In addition, it was necessary to remove undergrowth (herbicide or artificial weeding) in order to harvest Chinese hickory fruits **(Fig. S1ab)**. Not surprisingly, long-term intensive management resulted in soil acidification and negative effects on soil fertility and hickory tree health[32,33]. Therefore, it is necessary to better understand the spatio-temporal variation of soil properties in Chinese hickory plantation regions in order to guide sustainable Chinese hickory management. Although previous studies related to soil properties in Chinese hickory plantation regions were reported[34-36], the long-term dynamics and driving factors of soil fertility is limited. The objectives of our study were to (1) investigate the spatio-temporal variation of soil properties under long-term intensive management; (2) to explore the environmental factors influencing the changes in soil properties; (3) to evaluate the change of soil fertility in Chinese hickory plantation regions.

Results

Descriptive statistics. After logarithmic and Box-cox transformations, the soil properties all passed the K-S test ($K\text{-}S_P$ >0.05) (**Table 1**). The coefficient of variation (CV) values ranged from 10% to 130%. According to Fu et al reported[37], CV < 10%, between 10 and 90%, and > 90% indicate low, moderate and high variabilities, respectively. With the exception of available phosphorus (AP) concentrations for 2008 and 2018, which were highly variable, all other soil properties were moderately variable. The average pH was significantly higher in 2018 than that in 2008 (P <0.05). From 2008 to 2018, the average available nitrogen (AN) concentration declined by 38% (**Table 1**). The concentration of available potassium (AK) in 2018 was significantly higher than in 2013 **(Fig. S2)**. The variation ranges of AN and AP concentrations were significantly narrower in 2018 than in 2008 (**Table 1**). The soil pH was negatively correlated with AP and soil organic carbon (SOC) concentrations in 2008 and 2013 (P <0.01, **Fig. 2**). However, soil pH, AP and SOC were not correlated in 2018 **(Fig. 2)**. Correlations between AN, AP, AK and SOC in 2008-2018 were positive **(Fig. 2)**.

Spatial cluster and spatial outlier analysis. The local indicators of spatial correlation (LISA) maps (**Fig. 3**) indicated significant positive spatial autocorrelations for all soil properties (P <0.05). The local Moran's I results identified high-high spatial clusters of soil pH in the middle region of the study area, while low-low clusters of soil pH were distributed in the northwest region of the study area (Daoshi town) from 2008 to 2018 **(Fig. 3a-c)**. On the contrary, high-high clusters of AN, AP and SOC were mainly located in the northwest region of study area **(Fig. 3d-i, m-o)**. Meanwhile, high-high clusters of AK concentration shifted from northwest to northeast of the study area from 2013 to 2018 **(Fig. 3k-l)**.

To further describe the spatial structures of soil properties in 2008, 2013 and 2018, we calculated the semi-variances function of each study variable. and selected the best-fitted models and their related parameters (**Table 2**). The spatial dependencies (C_0/C_0+C) for soil pH, AN, AK and SOC were moderate and strong for AK in 2008 and 2013. The spatial autocorrelation for SOC was improved from 2008 to 2018 (**Table 2**). The ranges of soil properties varied from 0.16 km (AP) to 40.7 km (pH) in 2008, and from 0.13 km (AN) to 23.73 km (AP) in 2018, respectively.

The spatio-temporal distribution maps of soil properties were revealed by the ordinary Kriging interpolation method based on the semi-variance models for 2008, 2013 and 2018. The concentrations of AN, AP, AK and SOC had similar spatial distribution patterns (**Fig. 4d-o**), with high values mainly located in the northwest and northeast parts of the study area, while low values in the central and south regions. However, pH values showed an opposite spatial distribution pattern with a gradually increasing trend from north to south (**Fig. 4a-c**). Generally speaking, the spatial distributions of soil properties were similar to the above spatial clusters identified by local Moran's *I* (**Fig. 3**). Meanwhile, soil properties varied considerably from 2008 to 2018 (**Fig. S3**). The pH value generally increased, among which the pH value increased in Daoshi town, and Qingliangfeng town, while the pH value decreased in Tuankou town **(Fig. S3a-c).** The AN concentrations decreased from 213.82 mg kg^{-1} in 2008 to 43.50 mg kg^{-1} in 2018, among which the greatest decrease occurred in Daoshi town and Qingliangfeng town **(Fig. S3d-f).**

Control factors for soil properties. One way ANOVA analysis indicated that MAP and MAP have a significant influence on the change of pH (**Table S2**). What's more, altitude has significant influence on AP and SOC. However, most of soil properties was significantly influenced by anthropogenic factors such as fertilization, weeding, and harvesting methods (**Table S2**). This showed that the difference of comprehensive management mode, such as management method and intensity, will lead to the change of soil properties.

Soil fertility evaluation. The improved Nemerow method was used to evaluate the soil integrated fertility index (IFI) of Chinese hickory plantation, and the results were shown in **Fig. 5**. The soil fertility of Chinese hickory plantation was at medium level, but the IFI value decreased year by year, which was IFI=1.14 in 2008, IFI=1.08 in 2013 and IFI=1.06 in 2018, respectively. The IFI value in Daoshi town, Qingliangfeng town and Heqiao town and Tuankou town was relatively large in 2008 (**Fig. 5a**). However, in some areas of Daoshi town, soil fertility dropped from moderate to low in 2013 (**Fig. 5b**). In 2018, most parts of the study area declined to the low fertility level (IFI <0.9) (**Fig. 5c**). And compared with the previous two periods, Qingliangfeng town, Heqiao town and Tuankou town had the great reductions. Overall, soil fertility was at a moderate level in whole area during 2008-2018, but there were regional differences.

Discussion

Soil pH is a fundamental property that has significantly influences on numerous soil physical, chemical, biological properties and processes that affect plant growth and is therefore considered to be a key soil variable[38,39]. Our study showed that after 5 years intensive management caused significantly soil acidification (**Table 1**). This may be caused by excessive fertilizer application, atmospheric acid deposition, and fruit removal of base ions. Previous studies showed that long-term excessive application of nitrogen fertilizer will lead to the loss of calcium, magnesium and other base ions, directly leading to the production of H^+ in the soil[39,40]. SO_2 produced by industrial development and fossil burning and nitrogen oxides produced by agricultural production aggravate atmospheric acid deposition. What' more, other studies have shown that pecan harvesting removes base ions from the soil, leading to a drop in soil pH. However, compared with 2013, the pH value of the soil increased significantly in 2018 (**Table 1**). The increase in pH in 2018 was mainly contribute to the application of lime. Lime is a widely used worldwide to improve soil pH value and increase crop yields. Adequate lime input can raise the soil pH to a normal level, thereby eliminating the influence of Al and Mn on crops, and offsetting the leaching loss of base cations, thus increasing the soil pH[41].

According to the classification levels of the State Soil Survey Service of China (SSSSC 1996)[42], the concentration of AN more than 120 mg kg^{-1} can be considered as high level. In our study, the average concentration of AN were 190.08 mg kg^{-1} and 171.12 mg kg^{-1} in 2008 and 2013, respectively (**Table 1**). At the same time, Kriging interpolation analysis showed that high levels of AN were observed in almost the whole study area in 2008 and 2013 (**Fig. 4**). In the past decades, the massive consumption of nitrogen fertilizer has insured China produce enough grain to feed its growing population[43]. However, previous studies[44,45] have revealed that the efficiency of nitrogen fertilizer will decrease when the application rate exceeded the threshold (AN >120 mg kg^{-1}). Lei (2018)[46] showed that excessive accumulation of nitrogen in the soil would cause an increase in the incidence of dry rot in Chinese hickory plants, which could lead to plant death **(Fig. S4)**. In addition, excessive nitrogen input significantly increased the leaching of reactive nitrogen and gas emissions, causing environmental pollution. Therefore, farmers reduced the amount of nitrogen they applied to keep the Chinese hickory sustainable in 2018. According to LISA map, the distribution of AP presented a serious polarization phenomenon, while the high-high clusters were mainly distributed in the northeastern and the low-low clusters were mainly distributed in the southeastern of study area (**Fig. 3g-i**). Zhao et al[47] suggested that Chinese hickory plants might be P-deficient when soil available phosphorus was lower than 10.0 mg kg^{-1}. More serious, the average AP in the whole study area was less than 5 mg kg^{-1} from 2008 to 2018 indicating a severe phosphorus deficiency **(Table S1)**. This was related to the relatively low phosphorus concentration derived from the parent materials. But fundamentally speaking, the long-term high temperature and heavy rain in the south will cause serious phosphorus leaching. Therefore, farmers should pay attention to the dynamic change of AP and apply phosphorus fertilizer according to local conditions[48]. Tong et al[49] reported that when AK was higher than 100 mg kg^{-1} in soil, it could meet the requirements of carbohydrate transportation and fat synthesis during the growth period of Chinese hickory nuts. However, the AK <100 mg kg^{-1} were widely found in Daoshi town, Qingliangfeng town and Tuankou town **(Fig. 4l)**. Chinese hickory growing areas in these towns shared a common characteristic: it used to grow on steep slopes greater than 40 degrees and had serious soil erosion. This will cause potassium loss with water runoff or leaching to deep layers. Therefore, potassium should be replenished in time in these towns. Overall, in order to satisfy the nutrient requirement of the growth of Chinese hickory, it is necessary to apply soil experiment formula fertilizer.

SOC is commonly considered as an important indicator for evaluating soil fertility[50-53]. It can not only maintain and release soil nutrients, but also improve the physical structure of soil[54-56]. In our study, the concentration of SOC has significantly increased from 18.5 g kg^{-1} to 21.4 g kg^{-1} from 2008 to 2018 (**Fig. S2**). The CV in the concentration of SOC from 2013 to 2018 increased during the study period (**Table 1**). The concentration of SOC in Daoshi town had the largest variability **(Fig. S3m-o)**. According to field surveys, a large number of Chinese hickory plantation in Daoshi town have been abandoned in recent years, resulting in a thicker ground litter cover and understory. Previous studies showed that root-derived C additions were particularly effective in increasing the concentration of SOC[57-59]. This could be the main reason for the increase of SOC in Daoshi town. **Table 2** showed that SOC in 2008 and 2013 had moderate spatial dependence based on the "Nugget-to-sill" ratio, on the contrary, SOC showed a strong spatial dependence in 2018. This indicated that the spatial dependence of soil carbon in Chinese hickory plantation was more affected by internal factors than external factors with the increase of intensive agricultural management years. Moreover, **Table S2** showed that among the external factors, fertilization, weeding and harvesting methods all had extremely significant influence on SOC. Herbicide application was a common management method to reduce understory vegetation. The traditional method of collecting Chinese hickory fruit required that the ground be kept clean, so herbicides have been the first choice for farmers to clear undergrowth in the past **(Fig S1a-b)**. However, in recent years, due to the intensification of soil erosion, farmers have gradually changed their harvesting methods from knocking to laying nets **(Fig. S1a-d)**. This method reduced the application of herbicide and increased the input of exogenous C, which was beneficial to improve the content of SOC.

Materials and methods

Study area. The study area is located in Lin'an city (29º-31º N, 118º-120º E), Zhejiang province, southeastern China (**Fig. 1**). It is the largest production area of Chinese hickory, accounting for approximately 51% of the nationally planted areas[60]. The Chinese hickory planting densities range from 300 to 375 culm ha^{-1}, with an average diameter at breast height (DBH) of 12 cm and an average tree height of 8 m[61]. The area is characterized by subtropical monsoon climate with four distinct seasons, with the annual average temperature of 16°C and annual precipitation of 1628 mm. The annual average daylight hours are 1774 h with 235 d frost-free[62]. It has undulating topography with an elevation range of 150-1000 m[63]. The soil is derived from 7 major types of parent material, which include sandstone, sand shale, slate, phyllite, royolite, granite and quartz porphyry[64,65]. During the period of 2008-2010, 600-800 kg ha^{-1} of a compound fertilizer (N: P_2O_5: K_2O, 15:15:15) was applied every year[31]. From 2010 to 2018, the amount of fertilizer applied was reduced to 150-300 kg ha^{-1} per year. Typically, herbicide application and mowing were the main methods for controlling understory vegetation.

Field sampling and laboratory analysis. A grid of 1km × 1km was used, based on Chinese hickory plantation distribution in the Lin'an city. A total of 209 sample sites were established in 2008. For each site, a 20m × 20m plot was established. Five subsoil samples with a depth of 0-30 cm were collected according to the "Z" shape, which were further mixed into one soil sample, with a weight of 1 kg. For each sampling year, 209 soil samples were collected in situ in July of 2008, 2013 and 2018, respectively (**Fig. 1**). A portable global positioning system (GPS) was used to record the coordinates and altitude of each sampling location. Information on parent materials and forest age were recorded in 2008. The survey related to management measures (including fertilization, weeding and harvesting methods) of the Chinese hickory plantation regions was also carried out every 5 years. Annual average precipitation and annual average temperature information comes from the weather forecast network.

All soil samples were air-dried and sieved to 2-mm nylon mesh. A portion of each soil sample was ground with an agate mortar to pass the 0.149 mm nylon mesh, and sealed in an enclosed polyethylene bag. **S**oil pH was determined using an aqueous suspension at soil/water (*w/v*) ratio of 1:2.5. The soil AN was measured by a diffusion method. Soil AP and AK of soil samples were determined by Mo-Sb colorimetry and NH_4OAc extraction flame photometer, respectively. SOC was determined by the $K_2Cr_2O_7$-H_2SO_4 digestion, and titration with ammonium sulfate iron (Fe $(NH_4)_2(SO_4)_2\cdot 6H_2O$) solution.

Data analysis. *Descriptive statistics and difference tests.* The maximum, minimum, range, mean, standard deviation (SD), CV, kurtosis, skewness and significance test of sample indexes for 2008, 2013 and 2018 were presented. Test of normality for soil pH, AN, AP, AK, SOC was performed by the Kolmogorov–Smirnov (K-S) test[66]. None of the data were normally distributed. Therefore, the Box-Cox transformation of pH (2008 and 2013) and AK (2018) were performed to meet the assumption of normality using Matlab r2019a software. All other data were log transformed using SPSS (version 21.0). Kernel density estimation was used to estimate the distribution of the soil properties in all sample plots (package stats in R statistical software 4.0.0). One-way ANOVA was used to compare the differences in soil properties in 2008, 2013 and 2018. Pearson correlation analysis was used to identify the correlations between soil pH, AN, AP, AK and SOC[37]. An alpha level of 0.05 for significance testing was used in all statistical analyses, unless mentioned otherwise.

Spatial autocorrelation analyses. Spatial autocorrelation analysis is a statistical method to measure the cluster degree of spatial variables[67]. Moran's *I* is a commonly used index of spatial autocorrelation, which reflects the similarity between adjacent samples[68,69]. The global Moran's *I* was used to describe the soil properties autocorrelation feature over the entire regions (See **Supplementary material, Text S1** for detailed information).

Geostatistical analysis. The semi-variance (or variogram) is widely used in geostatistics to quantitatively describe the spatial variability of environmental variables, and this relationship was expressed through an effective variogram model, which can further provide input parameters for spatial interpolation of kriging[70] (See S**upplementary material, Text S2** for detailed information).

The ordinary Kriging method can be used to derive the optimal linear unbiased estimate of spatial variables[71]. The models that fit the semivariogram best according to the regression coefficient were determined. For the kriging interpolation, the transformed soil properties data were used. The ordinary kriging method was used to draw a spatial distribution map of soil properties and soil quality grade with ArcGIS desktop 10.7 (Esri Inc., Redlands, CA, USA).

Soil fertility evaluation. The calculation of Integrated Fertility Index (IFI) comprises three steps: (i) the selection of indicators, (ii) the calculation of the individual fertility index (IFI_i), and (iii) the calculation of IFI. The soil pH, AN, AP, AK and SOC were used in the calculations. To calculate the IFI the following equation was used:

$$\mathrm{IFI}_i = \begin{cases} \dfrac{x}{x_a} & x < x_a \\ 1 + \dfrac{(x - x_a)}{(x_b - x_a)} & x_a \le x \le x_b \\ 2 + \dfrac{(x - x_b)}{(x_c - x_b)} & x_a \le x \le x_b \\ 3 & x > x_c \end{cases} \qquad \text{equation (1)}$$

Where IFI_i is the individual fertility index; x is the measured value of each attribute[72]; x_a x_b and x_c are the upper and lower limits of each classification standard based on forest soils in Zhejiang (**Table S1**).

The final step was to calculate IFI using the improved Nemerow Quality Index equation:

$$\mathrm{IFI} = \sqrt{\frac{1}{2}(\mathrm{IFI}_{i\mathrm{ave}}^2 + \mathrm{IFI}_{i\mathrm{min}}^2)} \times (\frac{n-1}{n}) \qquad \text{equation (2)}$$

Where IFI is the soil integrated fertility index; $\mathrm{IFI}_{i\mathrm{ave}}$ is the average values for the individual fertility indices; $\mathrm{IFI}_{i\mathrm{min}}$ is the minimum value for the individual fertility indices; n is the number of soil properties[73]. The degree of IFI was classified as follows: IFI < 0.9; low, 0.9 ≤ IFI < 1.8; moderate, 1.8 ≤ IFI < 2.7; high, and IFI ≤ 2.7; very high.

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Author contributions

J.J., and L.W., analyzed statistically the data, composed figures and wrote the manuscript. J.W., K.Z., and W.F., designed and supervised all the experiment. K.M., H.W., and F.B., contributed to the data interpretation and to the revision of the final report. All authors contributed substantially to revisions.

Competing interests

The authors declare no competing interests.

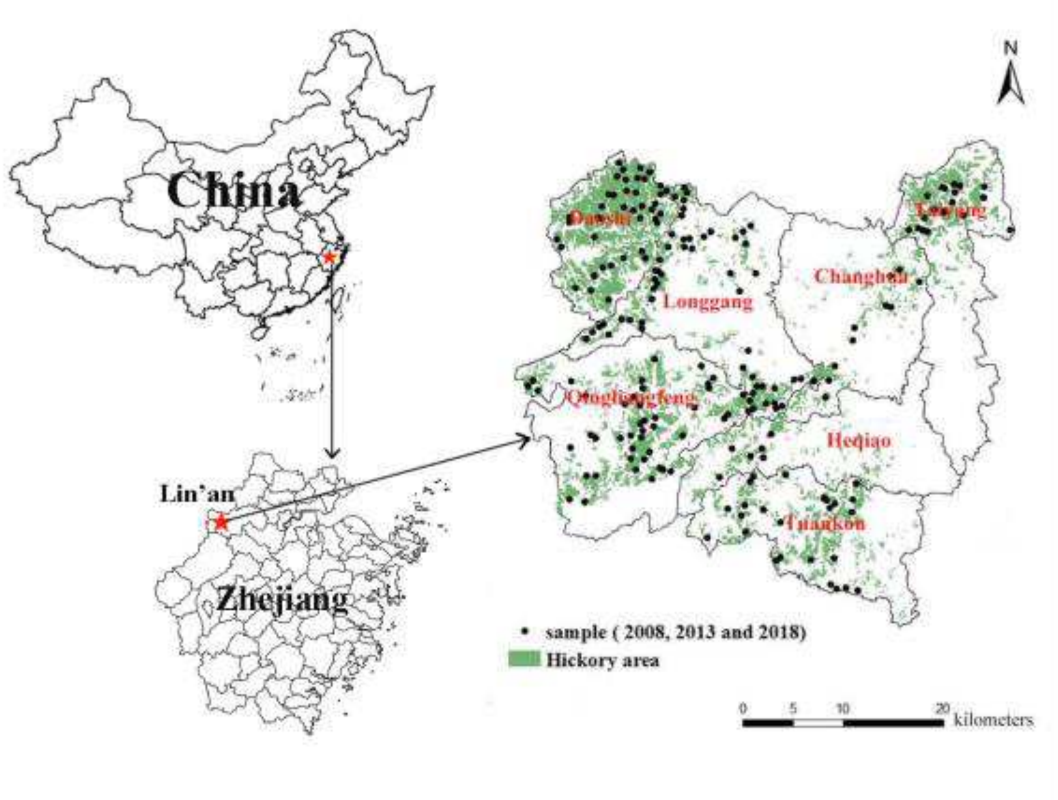

Figure 1. Location of the study area in Lin'an city, Zhejiang Province, China.

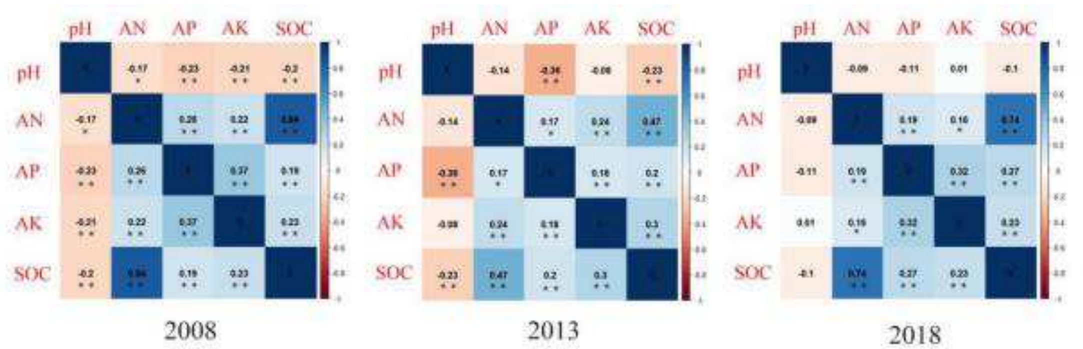

Figure 2. Pearson correlation among soil properties in 2008, 2013 and 2018. Color depicts the direction of the correlation (blue = positive, red = negative). P-values in black color are significant (* P < 0.05, ** P <0.01). The correlation coefficients are shown in the panel. AN: available nitrogen; AP: available phosphorus; AK: available potassium; SOC: soil organic carbon.

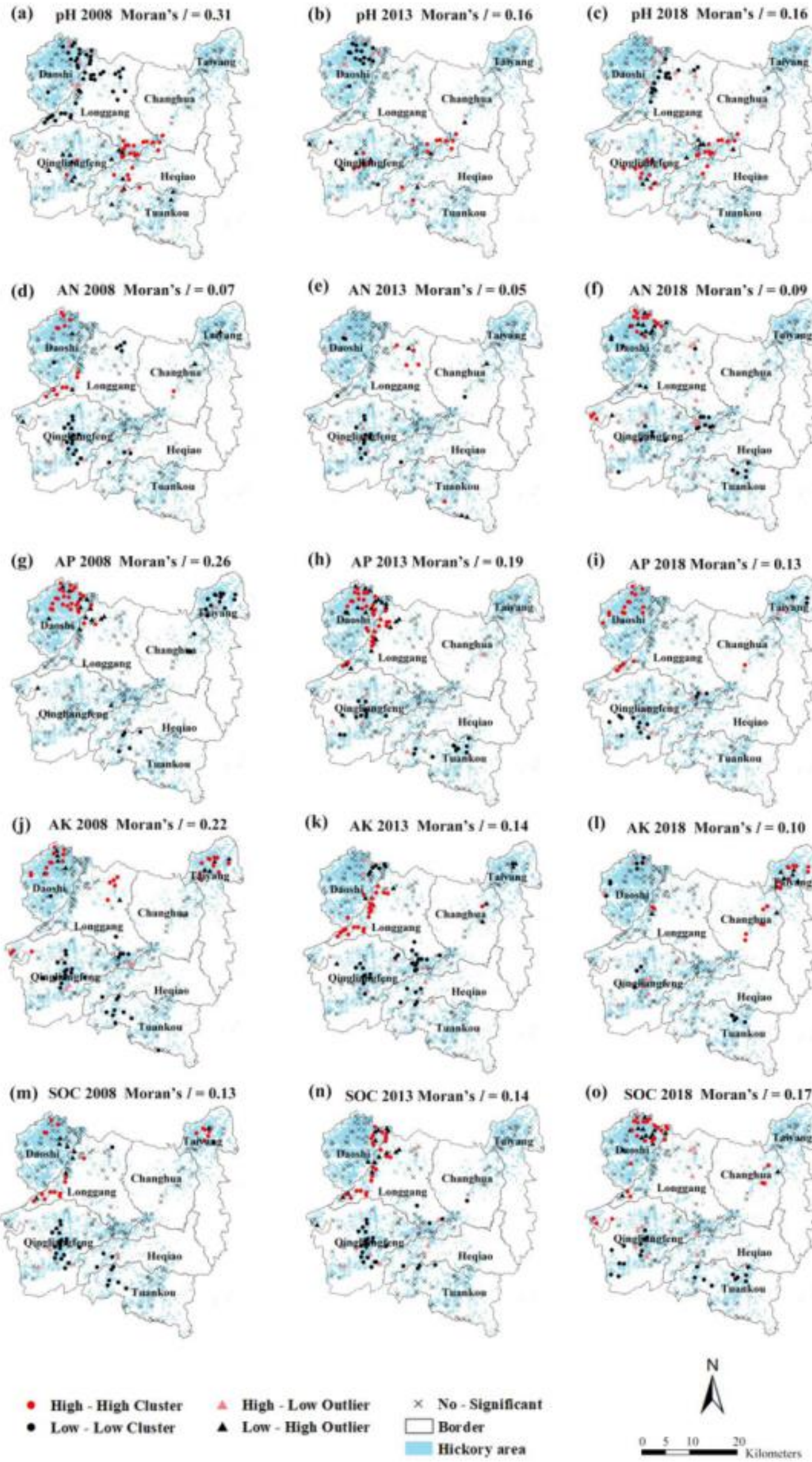

Figure 3. Local indicators of spatial correlation (LISA) maps of soil properties in Chinese hickory plantation regionss. AN: available nitrogen; AP: available phosphorus; AK: available potassium; SOC: soil organic carbon.

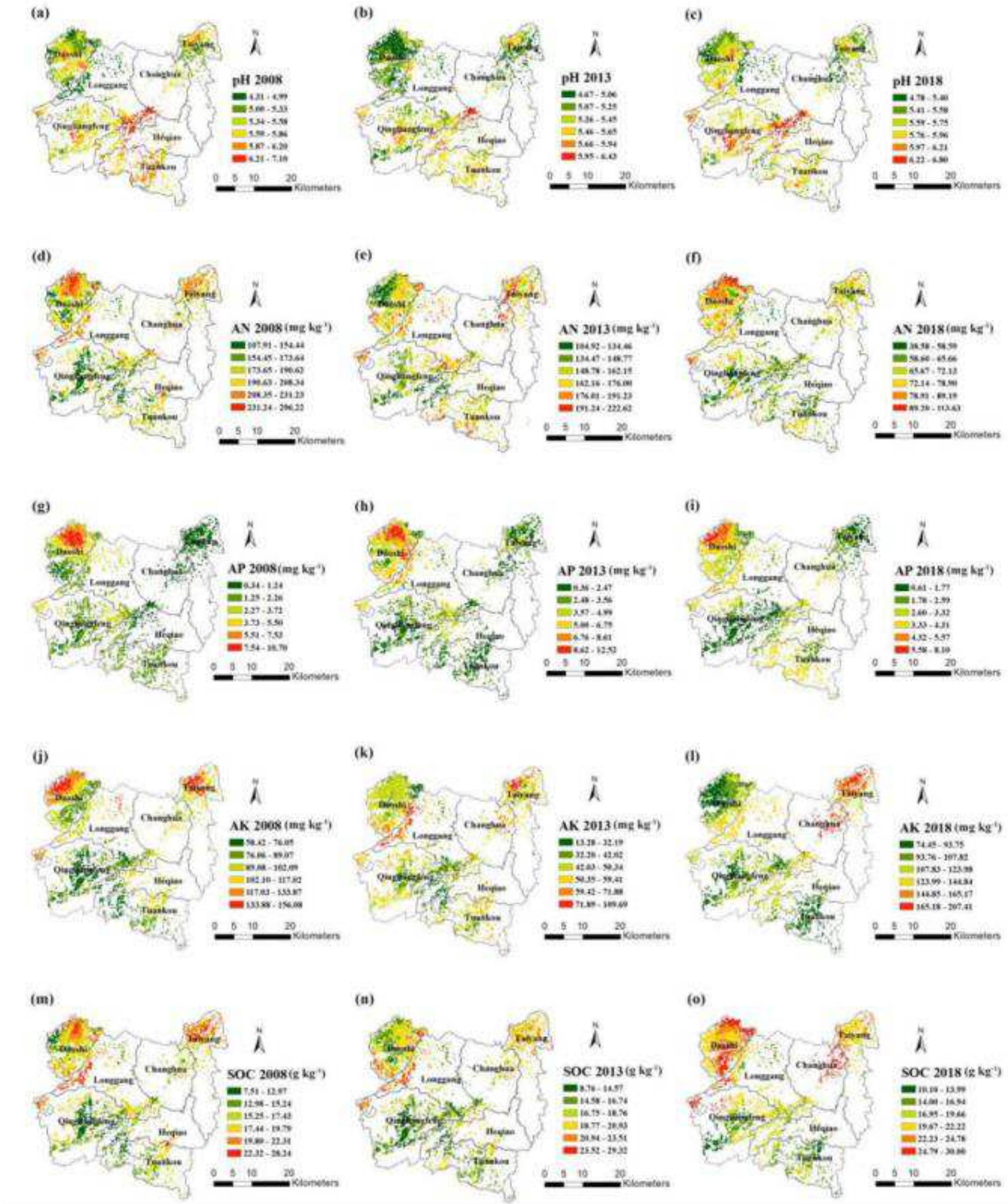

Figure 4. Spatial distribution maps of soil properties in Chinese hickory plantation regions. AN: available nitrogen; AP: available phosphorus; AK: available potassium; SOC: soil organic carbon.

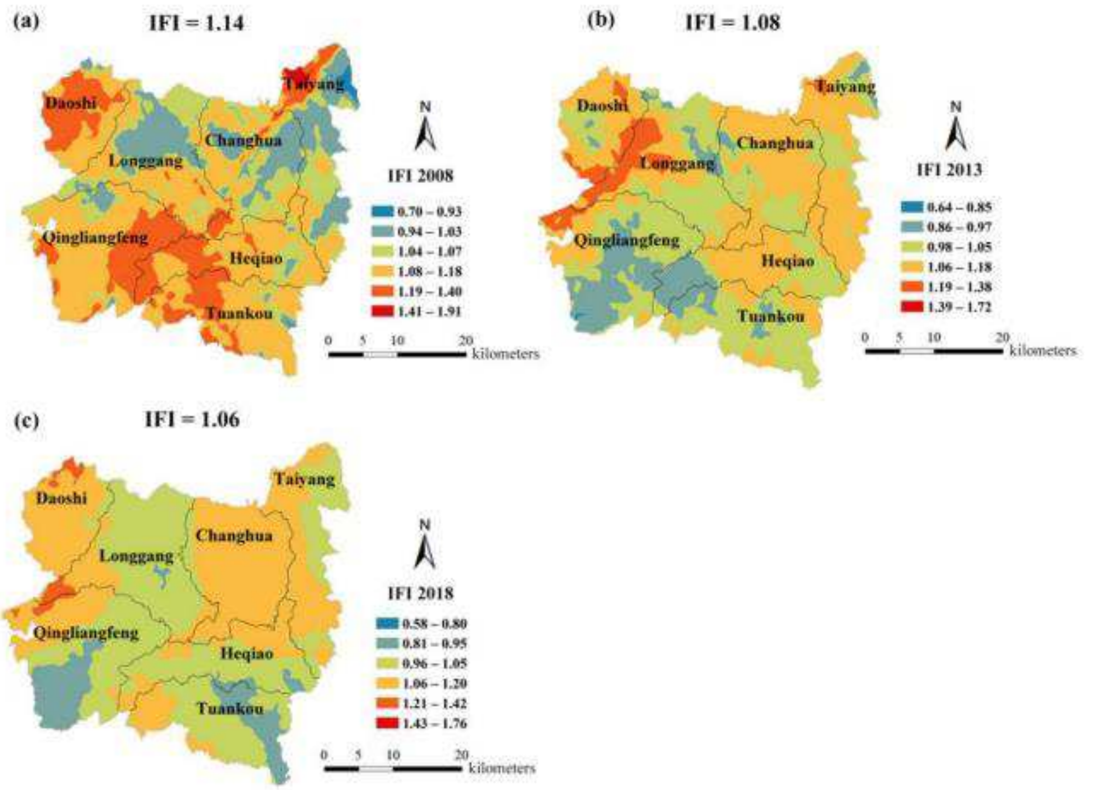

Figure 5. Soil integrated fertility index (IFI) level distribution map of the Chinese hickory plantation regions.

Table 1 Descriptive statistics of the soil attributes.

Attributes	Year	Minimum	Maximum	Range	CV%	Mean±SD	Skewness	Kurtosis	$K\text{-}S_p$
	2008	4.09	7.58	3.49	13.07	5.51±0.72b	0.241	-0.244	0.016 (0.2)
pH	2013	4.26	7.12	2.86	10.92	5.31±0.58c	0.038	-0.232	0.000 (0.2)
	2018	4.50	7.35	2.85	10.23	5.77±0.59a	0.015	-0.144	0.000 (0.2)
	2008	83.69	375.10	291.41	31.97	190.08±60.76a	-0.018	-0.345	0.030 (0.2)
AN (mg kg^{-1})	2013	36.21	348.30	312.09	32.21	171.12±55.12b	0.006	-0.125	0.000 (0.2)
	2018	24.50	147.31	122.81	32.54	71.89±23.39c	-0.122	0.151	0.001 (0.2)
	2008	0.04	21.20	21.16	129.60	3.75±4.86b	0.022	-0.405	0.000 (0.2)
AP (mg kg^{-1})	2013	0.10	15.84	15.74	82.50	4.40±3.63a	-0.694	1.122	0.000 (0.2)
	2018	0.06	15.44	15.38	91.25	4.00±3.65ab	0.064	-0.502	0.000 (0.2)
	2008	31.21	246.09	214.88	46.86	101.37±47.50a	0.064	-0.502	0.000 (0.2)
AK (mg kg^{-1})	2013	5.96	140.08	134.12	54.79	50.98±27.93b	0.157	-0.312	0.000 (0.2)
	2018	22.06	340.39	318.33	60.78	114.60±69.65a	-0.054	-0.747	0.000 (0.1)
	2008	3.06	42.42	39.36	40.28	18.32±7.38b	-0.398	0.687	0.000 (0.2)
SOC (g kg^{-1})	2013	6.06	38.66	32.60	34.62	18.34±6.35b	-0.153	-0.051	0.006 (0.2)
	2018	3.14	46.96	43.82	38.92	21.30±8.29a	-0.735	1.285	0.028 (0.08)

AN: available nitrogen; AP: available phosphorus; AK: available potassium; SOC: soil organic carbon. Different letters in the same variable indicate significant differences among years at $P < 0.05$ level. CV: coefficient of variation; $K\text{-}S_p$: significance level of Kolmogorov-Smirnov test for normality. The *K-Sp* values in brackets were calculated after transformation.

Table 2 Theoretical semi-variance models and their corresponding parameters of soil properties in 2008, 2013 and 2018.

Attributes	Theoretical model	Year	Nugget (C_0)	Sill (C_0+C)	Nugget/Sill	Range (km)	R^2
	Exponential	2008	0.36	0.71	0.51	40.70	0.91
pH	Exponential	2013	0.16	0.32	0.50	3.39	0.85
	Gaussian	2018	0.07	0.35	0.20	0.19	0.75
	Exponential	2008	1606.00	3642.00	0.44	2.16	0.76
AN (mg kg^{-1})	Exponential	2013	2845.30	3393.14	0.84	4.82	0.73
	Exponential	2018	111.00	633.80	0.18	0.13	0.50
	Exponential	2008	2.70	25.74	0.10	0.16	0.87
AP (mg kg^{-1})	Gaussian	2013	1.92	12.79	0.15	1.61	0.64
	Linear	2018	1.54	1.88	0.82	23.73	0.80
	Exponential	2008	1972.40	2784.92	0.71	0.85	0.85
AK (mg kg^{-1})	Exponential	2013	517.67	737.80	0.70	5.18	0.78
	Exponential	2018	1490.00	4981.00	0.30	3.78	0.81
	Gaussian	2008	42.60	85.21	0.50	17.42	0.88
SOC (g kg^{-1})	Gaussian	2013	34.00	68.01	0.50	23.21	0.84
	Gaussian	2018	0.10	65.99	0.002	5.40	0.91

AN: available nitrogen; AP: available phosphorus; AK: available potassium; SOC soil organic carbon.

Supplementary Files

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