

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

Jin Jin

Zhejiang A&F University

Luoqi Wang

Zhejiang A&F University

Karin Muller

The New Zealand Institute for Plant & Food Research Limited

Jiasen Wu (✉ jswu@zafu.edu.cn)

Zhejiang A&F University

Hailong Wang

Foshan University

Keli Zhao

Zhejiang A&F University

Frank Berninger

University of Eastern Finland

Weijun Fu

Zhejiang A&F University

Research Article

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

Posted Date: June 27th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-644353/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Scientific Reports on December 1st, 2021.

See the published version at <https://doi.org/10.1038/s41598-021-02947-z>.

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

4

5 **Jin Jin^{a,1}, Luoqi Wang^{a,1}, Karin Muller^b, Jiasen Wu^{a,*}, Hailong**
6 **Wang^c, Keli Zhao^a, Frank Berninger^d, Weijun Fu^{a,e,*}**

7

8 ^a State Key Laboratory of Subtropical Silviculture, Zhejiang A&F University, Hangzhou,
9 311300, China

10 ^b The New Zealand Institute for Plant & Food Research Limited, Ruakura Research Centre,
11 Private Bag, Hamilton, 3123, New Zealand

12 ^cBiochar Engineering Technology Research Center of Guangdong Province, School of
13 Environmental and Chemical Engineering, Foshan University, Foshan, 528000, China

14 ^dDepartment of Environmental and Biological Sciences, University of Eastern Finland, PO Box
15 111, Joensuu, 80101, Finland

16 ^e Zhejiang Provincial Key Laboratory of Carbon Cycling in Forest Ecosystems and Carbon
17 Sequestration, Zhejiang A&F University, Lin'an 311300, China

18

19 ¹These two authors contributed equally to this work.

20 *Corresponding authors: jswu@zafu.edu.cn; fuweijun@zafu.edu.cn

21 Tel.: +86-571-611-02592; Fax.: +86-571-610-81397

22 Number of text pages: 19 Number of figures: 5 Number of tables: 2

23 Submitted to: Scientific Reports

24 Type of paper: Regular paper (Original full-length research paper)

25

26

27

28

29

30

31

32 **Abstract**

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

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

50

51 **Introduction**

52 Soil plays an important role in ecosystem processes that control nutrient cycling. Long-term
53 monitoring of soil properties contributes to sustainable agricultural development, improving food
54 quality and safety, as well as to maintaining or improving soil fertility levels and avoiding soil
55 degradation¹. Numerous studies²⁻⁴ have been carried out in terrestrial ecosystems to study the factors
56 affecting soil properties. These factors can be categorised into external factors, such as altitude,
57 climate, topography, land use and management, internal factors, such as parent material, porosity,
58 microbe⁵⁻¹². Since 1980, with the implementation of China's reform and opening-up policy, Chinese
59 agriculture has changed with mechanized farming and chemical fertilization increasing¹³. And
60 long-term intensive agricultural management significantly changed soil pH, nutrient status, microbial
61 biomass and community composition¹⁴⁻¹⁷. In addition, over-or inappropriate fertilization has caused
62 various environmental problems, such as air pollution, water pollution, soil erosion, soil acidification
63 and biodiversity loss¹⁸⁻²⁰. This not only causes economic losses, but also has a negative impact on
64 environmental safety and human health²¹⁻²³.

65

66 China, the largest developing country in the world, has experienced a rapid shift from natural
67 vegetation lands into economic forests since the 1960s, due to an expanding human population.
68 Economic forests are widely distributed in China, with a total area of 20.57 million ha, accounting for
69 9% of the national forest area²⁴. Thus, economic forests are critical to promoting economic
70 development and participating in C balance at regional and national scales. However, such large-scale
71 land use change would markedly alter soil physio-chemical and biological properties²⁵. For example,
72 inappropriate management practices (pure forest management, deep ploughing and pruning) have led

73 to a reduction of soil microorganisms and the imbalance of soil nutrients²⁶⁻²⁹. Therefore, understanding
74 the effect of economic forest management practices on soil properties is much of importance to
75 achieve sustainable use of forest soil.

76

77 Chinese hickory is a unique edible nut and woody oil species that distributed in the Tianmu mountain
78 in Zhejiang province of southeastern China. Because of its unique taste and high nutritional value, the
79 area of Chinese hickory has reached 93,300 ha with a total yield of 31,500 t in 2018^{30,31}. For the
80 purpose of improving the yield of Chinese hickory, farmers have adopted intensive agricultural
81 management with extensive application of chemical fertilizer. In addition, it was necessary to remove
82 undergrowth (herbicide or artificial weeding) in order to harvest Chinese hickory fruits (**Fig. S1ab**).
83 Not surprisingly, long-term intensive management resulted in soil acidification and negative effects on
84 soil fertility and hickory tree health^{32,33}. Therefore, it is necessary to better understand the
85 spatio-temporal variation of soil properties in Chinese hickory plantation regions in order to guide
86 sustainable Chinese hickory management. Although previous studies related to soil properties in
87 Chinese hickory plantation regions were reported³⁴⁻³⁶, the long-term dynamics and driving factors of
88 soil fertility is limited. The objectives of our study were to (1) investigate the spatio-temporal variation
89 of soil properties under long-term intensive management; (2) to explore the environmental factors
90 influencing the changes in soil properties; (3) to evaluate the change of soil fertility in Chinese hickory
91 plantation regions.

92

93 Results

94 **Descriptive statistics.** After logarithmic and Box-cox transformations, the soil properties all passed
95 the K-S test ($K-S_p > 0.05$) (**Table 1**). The coefficient of variation (CV) values ranged from 10% to
96 130%. According to Fu et al reported³⁷, CV < 10%, between 10 and 90%, and > 90% indicate low,
97 moderate and high variabilities, respectively. With the exception of available phosphorus (AP)
98 concentrations for 2008 and 2018, which were highly variable, all other soil properties were
99 moderately variable. The average pH was significantly higher in 2018 than that in 2008 ($P < 0.05$).
100 From 2008 to 2018, the average available nitrogen (AN) concentration declined by 38% (**Table 1**).
101 The concentration of available potassium (AK) in 2018 was significantly higher than in 2013 (**Fig. S2**).
102 The variation ranges of AN and AP concentrations were significantly narrower in 2018 than in 2008
103 (**Table 1**). The soil pH was negatively correlated with AP and soil organic carbon (SOC)
104 concentrations in 2008 and 2013 ($P < 0.01$, **Fig. 2**). However, soil pH, AP and SOC were not correlated
105 in 2018 (**Fig. 2**). Correlations between AN, AP, AK and SOC in 2008-2018 were positive (**Fig. 2**).

106

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

115

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

122

123 The spatio-temporal distribution maps of soil properties were revealed by the ordinary Kriging
124 interpolation method based on the semi-variance models for 2008, 2013 and 2018. The concentrations
125 of AN, AP, AK and SOC had similar spatial distribution patterns (**Fig. 4d-o**), with high values mainly
126 located in the northwest and northeast parts of the study area, while low values in the central and south
127 regions. However, pH values showed an opposite spatial distribution pattern with a gradually
128 increasing trend from north to south (**Fig. 4a-c**). Generally speaking, the spatial distributions of soil
129 properties were similar to the above spatial clusters identified by local Moran's I (**Fig. 3**). Meanwhile,
130 soil properties varied considerably from 2008 to 2018 (**Fig. S3**). The pH value generally increased,
131 among which the pH value increased in Daoshi town, and Qingliangfeng town, while the pH value
132 decreased in Tuankou town (**Fig. S3a-c**). The AN concentrations decreased from 213.82 mg kg⁻¹ in
133 2008 to 43.50 mg kg⁻¹ in 2018, among which the greatest decrease occurred in Daoshi town and
134 Qingliangfeng town (**Fig. S3d-f**).

135

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

142

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

153

154 Discussion

155 Soil pH is a fundamental property that has significantly influences on numerous soil physical,
156 chemical, biological properties and processes that affect plant growth and is therefore considered to be

157 a key soil variable^{38,39}. Our study showed that after 5 years intensive management caused significantly
158 soil acidification (**Table 1**). This may be caused by excessive fertilizer application, atmospheric acid
159 deposition, and fruit removal of base ions. Previous studies showed that long-term excessive
160 application of nitrogen fertilizer will lead to the loss of calcium, magnesium and other base ions,
161 directly leading to the production of H⁺ in the soil^{39,40}. SO₂ produced by industrial development and
162 fossil burning and nitrogen oxides produced by agricultural production aggravate atmospheric acid
163 deposition. What' more, other studies have shown that pecan harvesting removes base ions from the
164 soil, leading to a drop in soil pH. However, compared with 2013, the pH value of the soil increased
165 significantly in 2018 (**Table 1**). The increase in pH in 2018 was mainly contribute to the application of
166 lime. Lime is a widely used worldwide to improve soil pH value and increase crop yields. Adequate
167 lime input can raise the soil pH to a normal level, thereby eliminating the influence of Al and Mn on
168 crops, and offsetting the leaching loss of base cations, thus increasing the soil pH⁴¹.

169

170 According to the classification levels of the State Soil Survey Service of China (SSSSC 1996)⁴², the
171 concentration of AN more than 120 mg kg⁻¹ can be considered as high level. In our study, the average
172 concentration of AN were 190.08 mg kg⁻¹ and 171.12 mg kg⁻¹ in 2008 and 2013, respectively (**Table 1**).
173 At the same time, Kriging interpolation analysis showed that high levels of AN were observed in
174 almost the whole study area in 2008 and 2013 (**Fig. 4**). In the past decades, the massive consumption
175 of nitrogen fertilizer has insured China produce enough grain to feed its growing population⁴³.
176 However, previous studies^{44,45} have revealed that the efficiency of nitrogen fertilizer will decrease
177 when the application rate exceeded the threshold (AN >120 mg kg⁻¹). Lei (2018)⁴⁶ showed that
178 excessive accumulation of nitrogen in the soil would cause an increase in the incidence of dry rot in
179 Chinese hickory plants, which could lead to plant death (**Fig. S4**). In addition, excessive nitrogen input
180 significantly increased the leaching of reactive nitrogen and gas emissions, causing environmental
181 pollution. Therefore, farmers reduced the amount of nitrogen they applied to keep the Chinese hickory
182 sustainable in 2018. According to LISA map, the distribution of AP presented a serious polarization
183 phenomenon, while the high-high clusters were mainly distributed in the northeastern and the low-low
184 clusters were mainly distributed in the southeastern of study area (**Fig. 3g-i**). Zhao et al⁴⁷ suggested
185 that Chinese hickory plants might be P-deficient when soil available phosphorus was lower than 10.0
186 mg kg⁻¹. More serious, the average AP in the whole study area was less than 5 mg kg⁻¹ from 2008 to
187 2018 indicating a severe phosphorus deficiency (**Table S1**). This was related to the relatively low
188 phosphorus concentration derived from the parent materials. But fundamentally speaking, the
189 long-term high temperature and heavy rain in the south will cause serious phosphorus leaching.
190 Therefore, farmers should pay attention to the dynamic change of AP and apply phosphorus fertilizer
191 according to local conditions⁴⁸. Tong et al⁴⁹ reported that when AK was higher than 100 mg kg⁻¹ in soil,
192 it could meet the requirements of carbohydrate transportation and fat synthesis during the growth
193 period of Chinese hickory nuts. However, the AK <100 mg kg⁻¹ were widely found in Daoshi town,
194 Qingliangfeng town and Tuankou town (**Fig. 4I**). Chinese hickory growing areas in these towns shared
195 a common characteristic: it used to grow on steep slopes greater than 40 degrees and had serious soil
196 erosion. This will cause potassium loss with water runoff or leaching to deep layers. Therefore,
197 potassium should be replenished in time in these towns. Overall, in order to satisfy the nutrient
198 requirement of the growth of Chinese hickory, it is necessary to apply soil experiment formula
199 fertilizer.

200

201 SOC is commonly considered as an important indicator for evaluating soil fertility⁵⁰⁻⁵³. It can not only
202 maintain and release soil nutrients, but also improve the physical structure of soil⁵⁴⁻⁵⁶. In our study, the
203 concentration of SOC has significantly increased from 18.5 g kg⁻¹ to 21.4 g kg⁻¹ from 2008 to 2018
204 (**Fig. S2**). The CV in the concentration of SOC from 2013 to 2018 increased during the study period
205 (**Table 1**). The concentration of SOC in Daoshi town had the largest variability (**Fig. S3m-o**).
206 According to field surveys, a large number of Chinese hickory plantation in Daoshi town have been
207 abandoned in recent years, resulting in a thicker ground litter cover and understory. Previous studies
208 showed that root-derived C additions were particularly effective in increasing the concentration of
209 SOC⁵⁷⁻⁵⁹. This could be the main reason for the increase of SOC in Daoshi town. **Table 2** showed that
210 SOC in 2008 and 2013 had moderate spatial dependence based on the "Nugget-to-sill" ratio, on the
211 contrary, SOC showed a strong spatial dependence in 2018. This indicated that the spatial dependence
212 of soil carbon in Chinese hickory plantation was more affected by internal factors than external factors
213 with the increase of intensive agricultural management years. Moreover, **Table S2** showed that among
214 the external factors, fertilization, weeding and harvesting methods all had extremely significant
215 influence on SOC. Herbicide application was a common management method to reduce understory
216 vegetation. The traditional method of collecting Chinese hickory fruit required that the ground be kept
217 clean, so herbicides have been the first choice for farmers to clear undergrowth in the past (**Fig S1a-b**).
218 However, in recent years, due to the intensification of soil erosion, farmers have gradually changed
219 their harvesting methods from knocking to laying nets (**Fig. S1a-d**). This method reduced the
220 application of herbicide and increased the input of exogenous C, which was beneficial to improve the
221 content of SOC.

222

223 **Materials and methods**

224 **Study area.** The study area is located in Lin'an city (29°-31° N, 118°-120° E), Zhejiang province,
225 southeastern China (**Fig. 1**). It is the largest production area of Chinese hickory, accounting for
226 approximately 51% of the nationally planted areas⁶⁰. The Chinese hickory planting densities range
227 from 300 to 375 culm ha⁻¹, with an average diameter at breast height (DBH) of 12 cm and an average
228 tree height of 8 m⁶¹. The area is characterized by subtropical monsoon climate with four distinct
229 seasons, with the annual average temperature of 16°C and annual precipitation of 1628 mm. The
230 annual average daylight hours are 1774 h with 235 d frost-free⁶². It has undulating topography with an
231 elevation range of 150-1000 m⁶³. The soil is derived from 7 major types of parent material, which
232 include sandstone, sand shale, slate, phyllite, roylite, granite and quartz porphyry^{64,65}. During the
233 period of 2008-2010, 600-800 kg ha⁻¹ of a compound fertilizer (N: P₂O₅: K₂O, 15:15:15) was applied
234 every year³¹. From 2010 to 2018, the amount of fertilizer applied was reduced to 150-300 kg ha⁻¹ per
235 year. Typically, herbicide application and mowing were the main methods for controlling understory
236 vegetation.

237

238 **Field sampling and laboratory analysis.** A grid of 1km × 1km was used, based on Chinese hickory
239 plantation distribution in the Lin'an city. A total of 209 sample sites were established in 2008. For each
240 site, a 20m × 20m plot was established. Five subsoil samples with a depth of 0-30 cm were collected
241 according to the "Z" shape, which were further mixed into one soil sample, with a weight of 1 kg. For

242 each sampling year, 209 soil samples were collected in situ in July of 2008, 2013 and 2018,
243 respectively (**Fig. 1**). A portable global positioning system (GPS) was used to record the coordinates
244 and altitude of each sampling location. Information on parent materials and forest age were recorded
245 in 2008. The survey related to management measures (including fertilization, weeding and harvesting
246 methods) of the Chinese hickory plantation regions was also carried out every 5 years. Annual average
247 precipitation and annual average temperature information comes from the weather forecast network.

248
249 All soil samples were air-dried and sieved to 2-mm nylon mesh. A portion of each soil sample was
250 ground with an agate mortar to pass the 0.149 mm nylon mesh, and sealed in an enclosed polyethylene
251 bag. Soil pH was determined using an aqueous suspension at soil/water (*w/v*) ratio of 1:2.5. The soil
252 AN was measured by a diffusion method. Soil AP and AK of soil samples were determined by Mo-Sb
253 colorimetry and NH₄OAc extraction flame photometer, respectively. SOC was determined by the
254 K₂Cr₂O₇-H₂SO₄ digestion, and titration with ammonium sulfate iron (Fe (NH₄)₂(SO₄)₂·6H₂O) solution.

255
256 **Data analysis.** *Descriptive statistics and difference tests.* The maximum, minimum, range, mean,
257 standard deviation (SD), CV, kurtosis, skewness and significance test of sample indexes for 2008,
258 2013 and 2018 were presented. Test of normality for soil pH, AN, AP, AK, SOC was performed by the
259 Kolmogorov–Smirnov (K-S) test⁶⁶. None of the data were normally distributed. Therefore, the
260 Box-Cox transformation of pH (2008 and 2013) and AK (2018) were performed to meet the
261 assumption of normality using Matlab r2019a software. All other data were log transformed using
262 SPSS (version 21.0). Kernel density estimation was used to estimate the distribution of the soil
263 properties in all sample plots (package stats in R statistical software 4.0.0). One-way ANOVA was
264 used to compare the differences in soil properties in 2008, 2013 and 2018. Pearson correlation analysis
265 was used to identify the correlations between soil pH, AN, AP, AK and SOC³⁷. An alpha level of 0.05
266 for significance testing was used in all statistical analyses, unless mentioned otherwise.

267
268 *Spatial autocorrelation analyses.* Spatial autocorrelation analysis is a statistical method to
269 measure the cluster degree of spatial variables⁶⁷. Moran's *I* is a commonly used index of
270 spatial autocorrelation, which reflects the similarity between adjacent samples^{68,69}. The
271 global Moran's *I* was used to describe the soil properties autocorrelation feature over the
272 entire regions (See **Supplementary material, Text S1** for detailed information).

273
274 *Geostatistical analysis.* The semi-variance (or variogram) is widely used in geostatistics to
275 quantitatively describe the spatial variability of environmental variables, and this
276 relationship was expressed through an effective variogram model, which can further
277 provide input parameters for spatial interpolation of kriging⁷⁰ (See **Supplementary**
278 **material, Text S2** for detailed information).

279
280 The ordinary Kriging method can be used to derive the optimal linear unbiased estimate
281 of spatial variables⁷¹. The models that fit the semivariogram best according to the
282 regression coefficient were determined. For the kriging interpolation, the transformed soil
283 properties data were used. The ordinary kriging method was used to draw a spatial

284 distribution map of soil properties and soil quality grade with ArcGIS desktop 10.7 (Esri
285 Inc., Redlands, CA, USA).

286

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

$$291 \quad \text{IFI}_i = \begin{cases} \frac{x}{x_a} & x < x_a \\ 1 + \frac{(x - x_a)}{(x_b - x_a)} & x_a \leq x \leq x_b \\ 2 + \frac{(x - x_b)}{(x_c - x_b)} & x_a \leq x \leq x_b \\ 3 & x > x_c \end{cases} \quad \text{equation (1)}$$

292 Where IFI_i is the individual fertility index; x is the measured value of each attribute⁷²; x_a , x_b and x_c are
293 the upper and lower limits of each classification standard based on forest soils in Zhejiang (**Table S1**).

294

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

$$296 \quad \text{IFI} = \sqrt{\frac{1}{2} (\text{IFI}_{i\text{ave}}^2 + \text{IFI}_{i\text{min}}^2)} \times \left(\frac{n-1}{n}\right) \quad \text{equation (2)}$$

297 Where IFI is the soil integrated fertility index; IFI_{iave} is the average values for the individual fertility
298 indices; IFI_{imin} is the minimum value for the individual fertility indices; n is the number of soil
299 properties⁷³. The degree of IFI was classified as follows: IFI < 0.9; low, 0.9 ≤ IFI < 1.8; moderate, 1.8
300 ≤ IFI < 2.7; high, and IFI ≤ 2.7; very high.

301

302 **References**

303

- 304 1 Brevik, E. C. & Sauer, T. J. The past, present, and future of soils and human health studies.
305 *SOIL* **1**, 35-46, doi:10.5194/soil-1-35-2015 (2015).
- 306 2 Liu, X., Zhang, W., Zhang, M., Ficklin, D. L. & Wang, F. Spatio-temporal variations of soil
307 nutrients influenced by an altered land tenure system in China. *Geoderma* **152**, 23-34,
308 doi:10.1016/j.geoderma.2009.05.022 (2009).
- 309 3 Tao, H. *et al.* Quantifying influences of interacting anthropogenic-natural factors on trace
310 element accumulation and pollution risk in karst soil. *Sci. Total Environ.* **721**,
311 doi:10.1016/j.scitotenv.2020.137770 (2020).
- 312 4 Xie, E. *et al.* Spatiotemporal variations in soil organic carbon and their drivers in southeastern
313 China during 1981-2011. *Soil Till. Res.* **205**, doi:10.1016/j.still.2020.104763 (2021).
- 314 5 Abegaz, A., Winowiecki, L. A., Vågen, T. G., Langan, S. & Smith, J. U. Spatial and temporal
315 dynamics of soil organic carbon in landscapes of the upper Blue Nile Basin of the Ethiopian

- 316 Highlands. *Agr. Ecosyst. Environ.* **218**, 190-208, doi:10.1016/j.agee.2015.11.019 (2016).
- 317 6 Jobbágy, E. G. & Jackson, R. B. The vertical distribution of soil organic carbon and its
318 relation to climate and vegetation. *Ecol. Appl.* **10**, 423-436,
319 doi:10.1890/1051-0761(2000)010[0423:TVDOSO]2.0.CO;2 (2000).
- 320 7 Liu, H. *et al.* Interactive effects of microplastics and glyphosate on the dynamics of soil
321 dissolved organic matter in a Chinese loess soil. *Catena* **182**,
322 doi:10.1016/j.catena.2019.104177 (2019).
- 323 8 Orgill, S. E. *et al.* Parent material and climate affect soil organic carbon fractions under
324 pastures in south-eastern Australia. *Soil Res.* **55**, 799-808, doi:10.1071/SR16305 (2017).
- 325 9 Song, C., Wang, E., Han, X. & Stirzaker, R. Crop production, soil carbon and nutrient
326 balances as affected by fertilisation in a Mollisol agroecosystem. *Nutr. Cycl. Agroecosys.* **89**,
327 363-374, doi:10.1007/s10705-010-9401-5 (2011).
- 328 10 Tang, M. *et al.* Elevational is the main factor controlling the soil microbial community
329 structure in alpine tundra of the Changbai Mountain. *Sci. Rep-uk.* **10**,
330 doi:10.1038/s41598-020-69441-w (2020).
- 331 11 Zhang, Y. *et al.* Soil organic carbon and total nitrogen stocks as affected by vegetation types
332 and altitude across the mountainous regions in the Yunnan Province, south-western China.
333 *Catena* **196**, doi:10.1016/j.catena.2020.104872 (2021).
- 334 12 Zhu, J., Wu, A. & Zhou, G. Spatial distribution patterns of soil total phosphorus influenced by
335 climatic factors in China's forest ecosystems. *Sci. rep-uk.* **11**, 5357,
336 doi:10.1038/s41598-021-84166-0 (2021).
- 337 13 Liu, D., Gong, Q.W., Yang, W.J. The evolution of farmland protection policy and optimization
338 path from 1978 to 2018. *China Rural Economy* **12**, 37-51 (2018) (in Chinese).
- 339 14 Cai, X. *et al.* Effects of conversion from a natural evergreen broadleaf forest to a Moso
340 bamboo plantation on the soil nutrient pools, microbial biomass and enzyme activities in a
341 subtropical area. *Forest Ecol. Manag.* **422**, 161-171, doi:10.1016/j.foreco.2018.04.022 (2018).
- 342 15 Fu, W. *et al.* Spatial variation of biomass carbon density in a subtropical region of
343 Southeastern China. *Forests* **6**, 1966-1981, doi:10.3390/f6061966 (2015).
- 344 16 Fu, W., Fu, Z., Zhao, K., Tunney, H. & Zhang, C. Variation of soil P and other nutrients in a
345 long-term grazed Grassland P experiment field. *Arch. Agron. Soil Sci.* **60**, 1459-1466,
346 doi:10.1080/03650340.2014.891018 (2014).
- 347 17 Wang, H. *et al.* Effects of long-term application of organic fertilizer on improving organic
348 matter content and retarding acidity in red soil from China. *Soil Till. Res.* **195**,
349 doi:10.1016/j.still.2019.104382 (2019).
- 350 18 Chen, S., Lin, B., Li, Y. & Zhou, S. Spatial and temporal changes of soil properties and soil
351 fertility evaluation in a large grain-production area of subtropical plain, China. *Geoderma*
352 **357**, doi:10.1016/j.geoderma.2019.113937 (2020).
- 353 19 Keesstra, S. *et al.* Effects of soil management techniques on soil water erosion in apricot
354 orchards. *Sci. Total Environ.* **551-552**, 357-366, doi:10.1016/j.scitotenv.2016.01.182 (2016).
- 355 20 Liu, M. *et al.* Nitrogen leaching greatly impacts bacterial community and denitrifiers
356 abundance in subsoil under long-term fertilization. *Agri. Ecosyst. Environ.* **294**,
357 doi:10.1016/j.agee.2020.106885 (2020).
- 358 21 Bogunovic, I., Trevisani, S., Seput, M., Juzbasic, D. & Durdevic, B. Short-range and regional

- 359 spatial variability of soil chemical properties in an agro-ecosystem in eastern Croatia. *Catena*
360 **154**, 50-62, doi:10.1016/j.catena.2017.02.018 (2017).
- 361 22 De Notaris, C., Rasmussen, J., Sørensen, P. & Olesen, J. E. Nitrogen leaching: A crop rotation
362 perspective on the effect of N surplus, field management and use of catch crops. *Agr. Ecosyst.*
363 *Environ.* **255**, 1-11, doi:10.1016/j.agee.2017.12.009 (2018).
- 364 23 Weier, K. L. Nitrogen use and losses in agriculture in subtropical Australia. *Fertil. Res.* **39**,
365 245-257, doi:10.1007/BF00750253 (1994).
- 366 24 Zhu Y.C. et al. Analysis of the economic forest development status, existing problems and
367 countermeasure in China. *China Forestry Economy* **03**, 89-91 (2020).
- 368 25 Han, C. et al. Effects of three coniferous plantation species on plant-soil feedbacks and soil
369 physical and chemical properties in semi-arid mountain ecosystems. *For. Ecosyst.* **8**,
370 doi:10.1186/s40663-021-00281-4 (2021).
- 371 26 Fang, X. et al. Forest-type shift and subsequent intensive management affected soil organic
372 carbon and microbial community in southeastern China. *Eur. J. Forest Res.* **136**, 689-697,
373 doi:10.1007/s10342-017-1065-0 (2017).
- 374 27 Li, Y. et al. Long-term intensive management effects on soil organic carbon pools and
375 chemical composition in Moso bamboo (*Phyllostachys pubescens*) forests in subtropical
376 China. *Forest Ecol. Manag.* **303**, 121-130, doi:10.1016/j.foreco.2013.04.021 (2013).
- 377 28 Wang, H. et al. Converting evergreen broad-leaved forests into tea and Moso bamboo
378 plantations affects labile carbon pools and the chemical composition of soil organic carbon.
379 *Sci. Total Environ.* **711**, doi:10.1016/j.scitotenv.2019.135225 (2020).
- 380 29 Xue, L. et al. Long term effects of management practice intensification on soil microbial
381 community structure and co-occurrence network in a non-timber plantation. *Forest Ecol.*
382 *Manag.* **459**, doi:10.1016/j.foreco.2019.117805 (2020).
- 383 30 Jia-Sen, W., Jin-Fang, Q., Zhi-Peng, T., Jian-Qin, H. & Ke-Li, Z. Changes in soil organic
384 carbon and soil microbial functional diversity of *Carya cathayensis* plantations under
385 intensive managements. *The journal of applied ecology.* **25** (2014).
- 386 31 Shen, Y.F. et al. Spatial-temporal variation of soil fertility in Chinese walnut (*Carya*
387 *cathayensis*) Plantation. *Scientia Silvae Sinicae* **52**, 1-12 (2016) (in Chinese).
- 388 32 Gao, Z., Liu, Z.Q. & Li, Y.N. Soil and water loss status and ecological restoration
389 countermeasures in Lin'an city, Zhejiang Province. Research. *Soil Water Conse.* **21**, 327-331
390 (2014) (in Chinese).
- 391 33 Huang, X.Z. et al. Comparison on soil physical and chemical properties at different vertical
392 zones of *Carya cathayensis* stands. *J. Zhejiang Forestry Sci. Technol.* **30**, 23-27 (2010) (in
393 Chinese).
- 394 34 Li, G. et al. Examining hickory plantation expansion and evaluating suitability for it using
395 multitemporal satellite imagery and ancillary data. *Appl. Geogr.* **109**,
396 doi:10.1016/j.apgeog.2019.102035 (2019).
- 397 35 Zhang, M. et al. Difference in pH value and nutrient and bacterial diversity in the *carya*
398 *cathayensis* forest soil under different management models. *Biodivers. Sci.* **26**, 611-619,
399 doi:10.17520/biods.2017268 (2018).
- 400 36 Dong, J.H. et al. Soil Fertility of *Carya cathayensis* plantations on different geological strata.
401 *J. Zhejiang Forestry Sci. Technol.* **38**, 14-20 (2018) (in Chinese).

- 402 37 Fu, W. J., Jiang, P. K., Zhou, G. M. & Zhao, K. L. Using Moran's i and GIS to study the
403 spatial pattern of forest litter carbon density in a subtropical region of southeastern China.
404 *Biogeosciences* **11**, 2401-2409, doi:10.5194/bg-11-2401-2014 (2014).
- 405 38 Fu, C. *et al.* Spatial interpolation of orchard soil pH using soil type and planting duration as
406 auxiliary information. *Pedosphere* **30**, 628-637, doi:10.1016/S1002-0160(18)60045-1 (2020).
- 407 39 Liu, Z. P., Shao, M. A. & Wang, Y. Q. Large-scale spatial interpolation of soil pH across the
408 Loess Plateau, China. *Environ. Earth Sci.* **69**, 2731-2741, doi:10.1007/s12665-012-2095-z
409 (2013).
- 410 40 Hao, T. *et al.* Impacts of nitrogen fertilizer type and application rate on soil acidification rate
411 under a wheat-maize double cropping system. *J. Environ. Manage.* **270**,
412 doi:10.1016/j.jenvman.2020.110888 (2020).
- 413 41 Xu, D., Carswell, A., Zhu, Q., Zhang, F. & de Vries, W. Modelling long-term impacts of
414 fertilization and liming on soil acidification at Rothamsted experimental station. *Sci.Total*
415 *Environ.* **713**, doi:10.1016/j.scitotenv.2019.136249 (2020).
- 416 42 State Soil Survey Service of China (SSSC). (1996) Dataset of National Soil Survey of China.
417 *China Agriculture Press*, Beijing 103-122 (in Chinese).
- 418 43 Liu, H. *et al.* Impact of herbicide application on soil erosion and induced carbon loss in a
419 rubber plantation of Southwest China. *Catena* **145**, 180-192,
420 doi:10.1016/j.catena.2016.06.007 (2016).
- 421 44 Geisseler, D. & Scow, K. M. Long-term effects of mineral fertilizers on soil microorganisms -
422 A review. *Soil Biol. Biochem.* **75**, 54-63, doi:10.1016/j.soilbio.2014.03.023 (2014).
- 423 45 Zhao, H., Li, X. & Jiang, Y. Response of nitrogen losses to excessive nitrogen fertilizer
424 application in intensive greenhouse vegetable production. *Sustainability-Basel* **11**,
425 doi:10.3390/su11061513 (2019).
- 426 46 Lei, Y.C. *et al.* Relationship between soil chemical properties and canker disease of *Carya*
427 *cathayensis*. Zhejiang A&F University (2018) (in Chinese).
- 428 47 Zhao, W.M. *et al.* Soil phosphorus status and leaching risk analysis of walnut forest land in
429 Lin 'an. *Acta agriculturae Zhejiangensis*, **26**, 154-158. (2014).
- 430 48 Liu, Z. *et al.* A simple assessment on spatial variability of rice yield and selected soil chemical
431 properties of paddy fields in South China. *Geoderma* **235-236**, 39-47,
432 doi:10.1016/j.geoderma.2014.06.027 (2014).
- 433 49 Tong, G.P. *et al.* Seasonal changes of soil and leaf nutrient levels in a *Carya cathayensis*
434 orchard. *J. Zhejiang forestry U.* **26**, 516-521 (2009).
- 435 50 Li, J., Zhang, D. & Liu, M. Factors controlling the spatial distribution of soil organic carbon
436 in Daxing'anling Mountain. *Sci. rep-uk.* **10**, doi:10.1038/s41598-020-69590-y (2020).
- 437 51 Li, P., Wang, Q., Endo, T., Zhao, X. & Kakubari, Y. Soil organic carbon stock is closely
438 related to aboveground vegetation properties in cold-temperate mountainous forests.
439 *Geoderma* **154**, 407-415, doi:10.1016/j.geoderma.2009.11.023 (2010).
- 440 52 Tiessen, H., Cuevas, E. & Chacon, P. The role of soil organic matter in sustaining soil fertility.
441 *Nature* **371**, 783-785, doi:10.1038/371783a0 (1994).
- 442 53 Xu, H. & Zhang, C. Investigating spatially varying relationships between total organic carbon
443 contents and pH values in European agricultural soil using geographically weighted
444 regression. *Sci. Total Environ.* **752**, doi:10.1016/j.scitotenv.2020.141977 (2021).

- 445 54 Fernandes, M. M. H., Coelho, A. P., Fernandes, C., Silva, M. F. D. & Dela Marta, C. C.
446 Estimation of soil organic matter content by modeling with artificial neural networks.
447 *Geoderma* **350**, 46-51, doi:10.1016/j.geoderma.2019.04.044 (2019).
- 448 55 Stockmann, U. *et al.* Global soil organic carbon assessment. *Glob. Food Secur.* **6**, 9-16,
449 doi:10.1016/j.gfs.2015.07.001 (2015).
- 450 56 Wood, S. A., Tirfessa, D. & Baudron, F. Soil organic matter underlies crop nutritional quality
451 and productivity in smallholder agriculture. *Agr. Ecosyst. Environ.* **266**, 100-108,
452 doi:10.1016/j.agee.2018.07.025 (2018).
- 453 57 Jackson, R.B. *et al.* The ecology of soil carbon: pools, vulnerabilities, and biotic and abiotic
454 controls. *Annu. Rev. Ecol. Evol. S.* **48**, 419-445. doi: 10.1146/annurev-ecolsys-112414-054234
455 (2017).
- 456 58 Midwood, A. J. *et al.* Importance of drive-row vegetation for soil carbon storage in woody
457 perennial crops: A regional study. *Geoderma* **377**, doi:10.1016/j.geoderma.2020.114591
458 (2020).
- 459 59 Schillaci, C. *et al.* Spatio-temporal topsoil organic carbon mapping of a semi-arid
460 Mediterranean region: The role of land use, soil texture, topographic indices and the influence
461 of remote sensing data to modelling. *Sci. Total Environ.* **601-602**, 821-832,
462 doi:10.1016/j.scitotenv.2017.05.239 (2017).
- 463 60 Xi, Z., Lu, D., Liu, L. & Ge, H. Detection of drought-induced hickory disturbances in western
464 Lin an county, China, using multitemporal Landsat imagery. *Remote Sens.-basel.* **8**,
465 doi:10.3390/rs8040345 (2016).
- 466 61 Wu, J., Lin, H., Meng, C., Jiang, P. & Fu, W. Effects of intercropping grasses on soil organic
467 carbon and microbial community functional diversity under Chinese hickory (*Carya*
468 *cathayensis* Sarg.) stands. *Soil Res.* **52**, 575-583, doi:10.1071/SR14021 (2014).
- 469 62 Wu, W. *et al.* Soil organic carbon content and microbial functional diversity were lower in
470 monospecific Chinese hickory stands than in natural Chinese hickory-broad-leaved mixed
471 forests. *Forests* **10**, doi:10.3390/f10040357 (2019).
- 472 63 Wu, J. *et al.* Effect of 26 years of intensively managed *Carya cathayensis* stands on soil
473 organic carbon and fertility. *Sci. World J.* **2014**, doi:10.1155/2014/857641 (2014).
- 474 64 Micheli, E., Schad, P., Spaargaren, O., Dent, D. & Wrb, I. W. *World reference base for soil*
475 *resources: 2006: a framework for international classification, correlation and*
476 *communication.* (World reference base for soil resources: 2006: a framework for
477 international classification, correlation and communication, 2006).
- 478 65 Dong, L.L. *et al.* Changes of soil physical-chemical properties derived from different parent
479 materials/rocks in Karst Mountain. *Chinese J. Soil Sci.* **03**, 471-474 (2008) (in Chinese).
- 480 66 Dai, W. *et al.* Spatial variation of organic carbon density in topsoils of a typical subtropical
481 forest, southeastern China. *Catena* **167**, 181-189, doi:10.1016/j.catena.2018.04.040 (2018).
- 482 67 Bocquet-Appel, J. P. & Bacro, J. N. Isolation by distance, trend surface analysis, and spatial
483 autocorrelation. *Hum. biol. an international record of research* **65**, 11-27 (1993).
- 484 68 Fu, W., Zhao, K., Zhang, C. & Tunney, H. Using Moran's I and geostatistics to identify spatial
485 patterns of soil nutrients in two different long-term phosphorus-application plots. *J. Plant*
486 *Nutr. Soil Sci.* **174**, 785-798, doi:10.1002/jpln.201000422 (2011).
- 487 69 Zhao, K. *et al.* Spatial variations of concentrations of copper and its speciation in the soil-rice

- 488 system in Wenling of southeastern China. *Environ. Sci. Pollut. R.* **21**, 7165-7176,
489 doi:10.1007/s11356-014-2638-9 (2014).
- 490 70 Zhao, K. *et al.* Risk assessment, spatial patterns and source apportionment of soil heavy
491 metals in a typical Chinese hickory plantation region of southeastern China. *Geoderma* **360**,
492 doi:10.1016/j.geoderma.2019.114011 (2020).
- 493 71 Chen, T. *et al.* Identification of trace element sources and associated risk assessment in
494 vegetable soils of the urban-rural transitional area of Hangzhou, China. *Environ. Pollut.* **151**,
495 67-78, doi:10.1016/j.envpol.2007.03.004 (2008).
- 496 72 Kan, W.J., Wu, Q.T. A preliminary study on a quantitative and comprehensive method for
497 evaluating soil fertility. *Chinese J. Soil Sci.* **06**, 245-247 (1994) (in Chinese).
- 498 73 Yang, M., Mouazen, A., Zhao, X. & Guo, X. Assessment of a soil fertility index using visible
499 and near-infrared spectroscopy in the rice paddy region of southern China. *Eur. J. Soil Sci.* **71**,
500 615-626, doi:10.1111/ejss.12907 (2020).

501

502 **Acknowledgements**

503 This work was financially supported by the Natural Science Foundation of Zhejiang Province (No.
504 LY20C160004). The authors declare no conflict of interest.

505

506 **Author contributions**

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

510

511 **Competing interests**

512 The authors declare no competing interests.

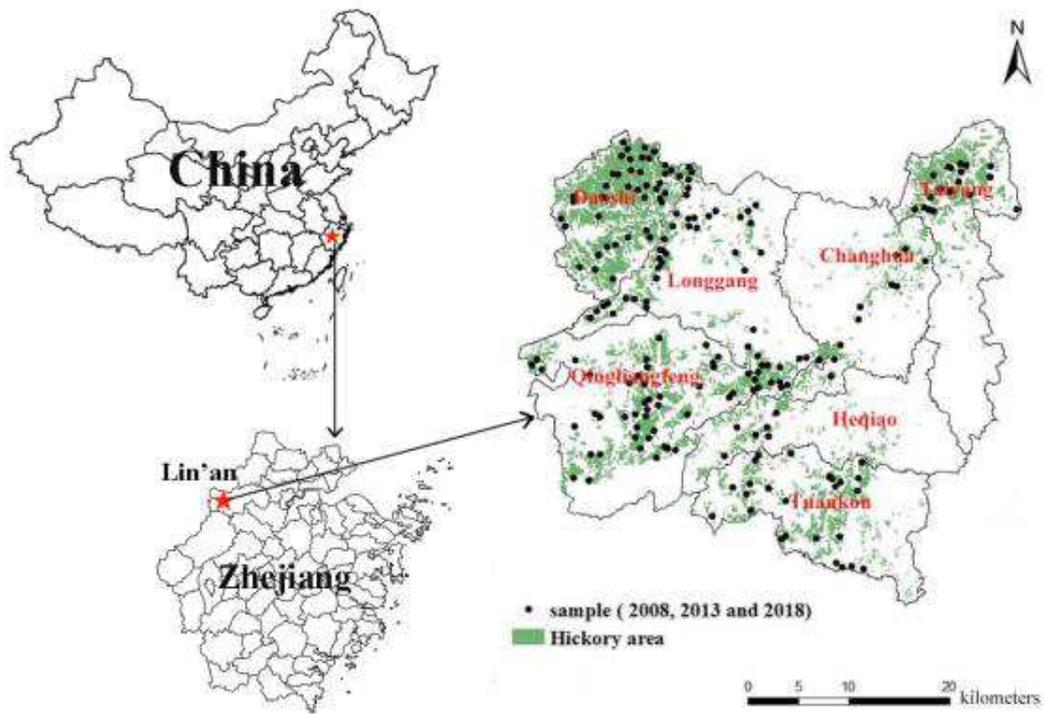
513

514

515

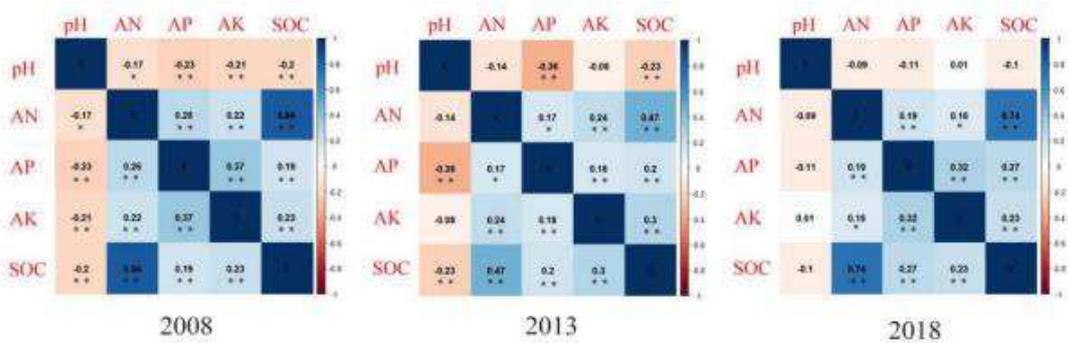
516

517

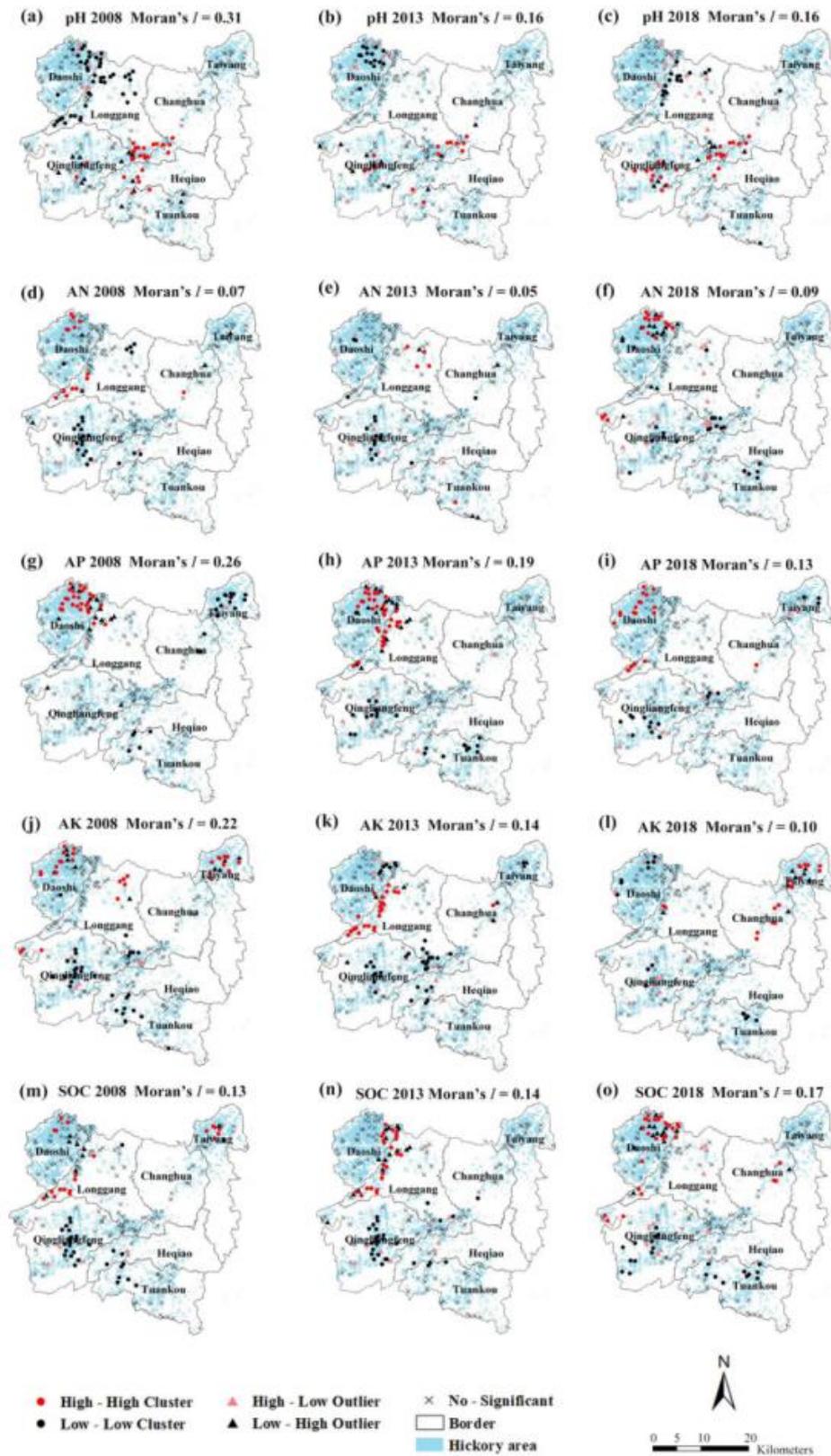


518
 519 **Figure 1.** Location of the study area in Lin'an city, Zhejiang Province, China.

520
 521
 522
 523

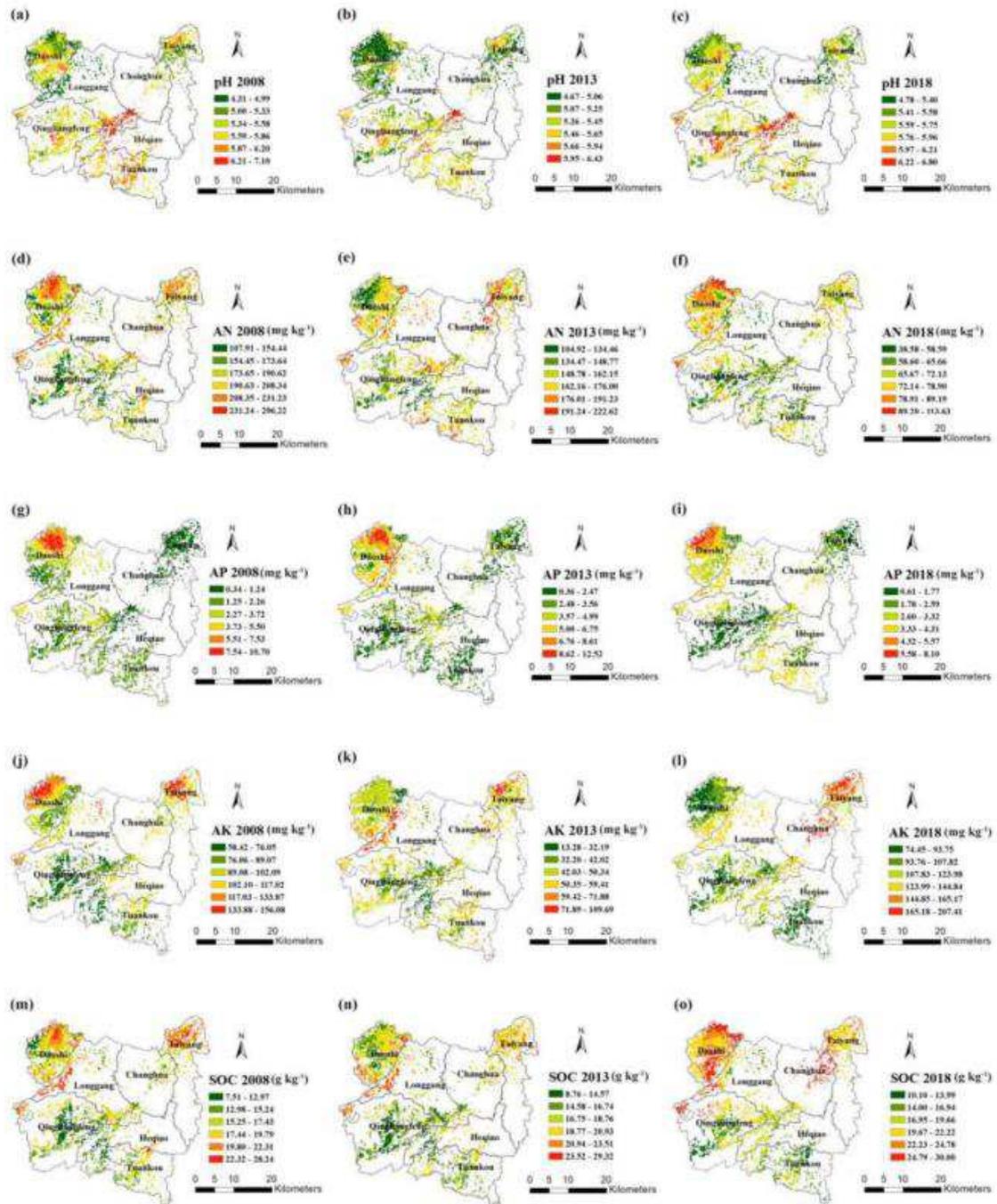


524
 525 **Figure 2.** Pearson correlation among soil properties in 2008, 2013 and 2018. Color depicts the
 526 direction of the correlation (blue = positive, red = negative). P-values in black color are significant (*
 527 $P < 0.05$, ** $P < 0.01$). The correlation coefficients are shown in the panel. AN: available nitrogen; AP:
 528 available phosphorus; AK: available potassium; SOC: soil organic carbon.



529

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



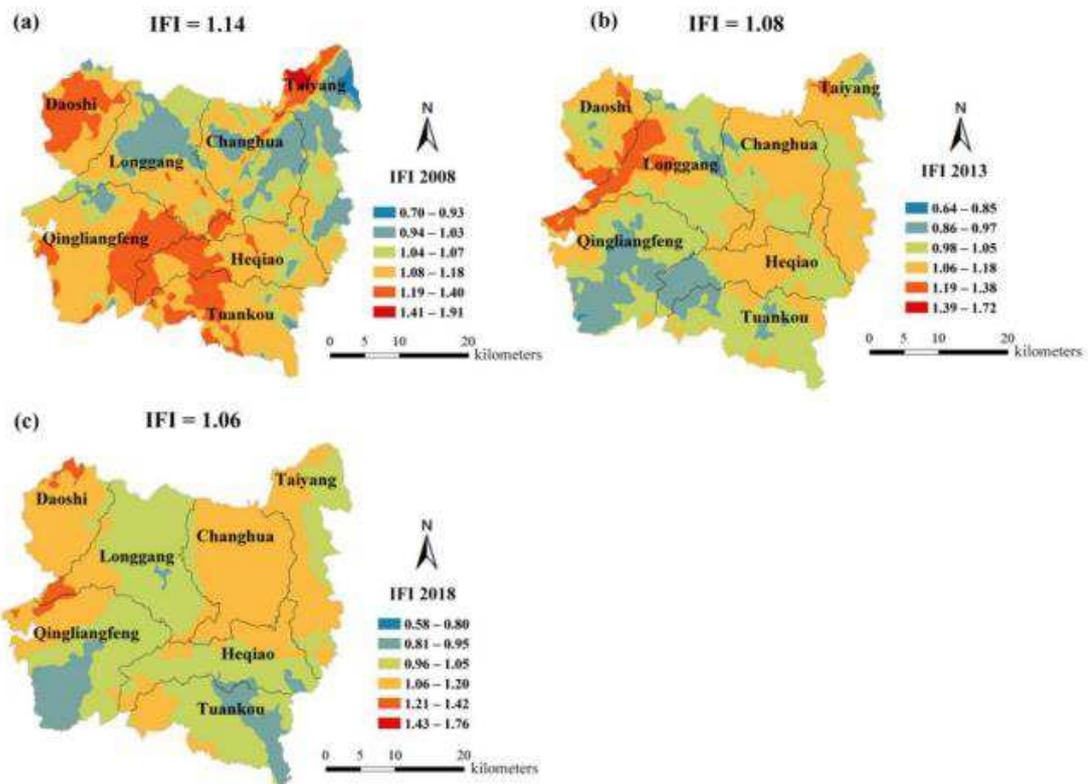
533

534

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

537

538



539

540

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

543

544

545

546

547

548

549

550

551

552

553

554

555

556

557

558

559

560

561

562 **Table 1** Descriptive statistics of the soil attributes.

Attributes	Year	Minimum	Maximum	Range	CV%	Mean±SD	Skewness	Kurtosis	<i>K-S_p</i>
pH	2008	4.09	7.58	3.49	13.07	5.51±0.72b	0.241	-0.244	0.016 (0.2)
	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)
AN (mg kg ⁻¹)	2008	83.69	375.10	291.41	31.97	190.08±60.76a	-0.018	-0.345	0.030 (0.2)
	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)
AP (mg kg ⁻¹)	2008	0.04	21.20	21.16	129.60	3.75±4.86b	0.022	-0.405	0.000 (0.2)
	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)
AK (mg kg ⁻¹)	2008	31.21	246.09	214.88	46.86	101.37±47.50a	0.064	-0.502	0.000 (0.2)
	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)
SOC (g kg ⁻¹)	2008	3.06	42.42	39.36	40.28	18.32±7.38b	-0.398	0.687	0.000 (0.2)
	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)

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

566 **Table 2** Theoretical semi-variance models and their corresponding parameters of soil properties in
 567 2008, 2013 and 2018.

Attributes	Theoretical model	Year	Nugget (C ₀)	Sill (C ₀ +C)	Nugget/Sill	Range (km)	R ²
pH	Exponential	2008	0.36	0.71	0.51	40.70	0.91
	Exponential	2013	0.16	0.32	0.50	3.39	0.85
	Gaussian	2018	0.07	0.35	0.20	0.19	0.75
AN (mg kg ⁻¹)	Exponential	2008	1606.00	3642.00	0.44	2.16	0.76
	Exponential	2013	2845.30	3393.14	0.84	4.82	0.73
	Exponential	2018	111.00	633.80	0.18	0.13	0.50
AP (mg kg ⁻¹)	Exponential	2008	2.70	25.74	0.10	0.16	0.87
	Gaussian	2013	1.92	12.79	0.15	1.61	0.64
	Linear	2018	1.54	1.88	0.82	23.73	0.80
AK (mg kg ⁻¹)	Exponential	2008	1972.40	2784.92	0.71	0.85	0.85
	Exponential	2013	517.67	737.80	0.70	5.18	0.78
	Exponential	2018	1490.00	4981.00	0.30	3.78	0.81
SOC (g kg ⁻¹)	Gaussian	2008	42.60	85.21	0.50	17.42	0.88
	Gaussian	2013	34.00	68.01	0.50	23.21	0.84
	Gaussian	2018	0.10	65.99	0.002	5.40	0.91

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

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Supplementarymaterial.pdf](#)