Leaf element concentrations of terrestrial plants across China are influenced by taxonomy and the environment

Shi-Bao Zhang, Jiao-Lin Zhang, J. W. Ferry Slik and Kun-Fang Cao*

ABSTRACT

Aim The productivity, functioning and biogeochemical cycles of terrestrial ecosystems are strongly affected by leaf element concentrations. Understanding the biological and ecological factors affecting leaf element concentrations is therefore important for modelling the productivity and nutrient fluxes of ecosystems and their responses to global change. The present study aimed to determine how leaf element concentrations are linked to taxonomy and the environment.

Location China.

Methods The concentrations of 10 leaf elements of 702 terrestrial plant species from different biomes were extracted from publications. The links between environmental variables, taxonomy and leaf elements were analyzed using phylogenetically comparative methods and partial Mantel tests.

Results Taxonomy had stronger effects on leaf S and SiO$_2$ than latitude, explaining 40.2–43.9% of total variation, whereas latitude had stronger effects on leaf N, P, K, Fe, Al, Mn, Na and Ca concentrations, explaining 19.5–52.1% of total variation. Leaf N, S, Al, Fe and Na concentrations were correlated with mean annual precipitation (MAP), while leaf N, P and Fe concentrations were correlated with mean annual temperature (MAT). Latitude, MAP and MAT were significantly correlated with the first axis of a principal components analysis (PCA). This first axis was associated with leaf elements involved in protein synthesis and photosynthesis. The other PCA axes, which were not correlated with MAT, latitude and MAP, were associated with leaf elements responsible for cell structure and enzymes.

Main conclusions Leaf element concentrations of terrestrial plants in China were correlated with climate, latitude and taxonomy. With the exception of S and SiO$_2$, the environmental factors were more important in explaining leaf element variation than taxonomy. Therefore, changes in temperature and precipitation will directly affect the spatial patterns of leaf elements and thus the associated nutrient fluxes and ecosystem functioning.

Keywords Biogeography, China, climate, latitudinal gradient, leaf element, Mantel test, phylogenetically comparative method, taxonomy.
of the response of vegetation to global change (Fyllas et al., 2009; Ordoñez et al., 2009).

Spatial patterns of soil nutrients are influenced by soil substrate, climate and biological factors (Xiong & Li, 1987; Ordoñez et al., 2009). Acid soils have lower concentrations of potassium (K), Ca, magnesium (Mg) and phosphorus (P), but are rich in aluminium (Al) and iron (Fe). In contrast, alkaline soils are deficient in manganese (Mn), Fe and P (Xiong & Li, 1987). Leaf element concentrations depend strongly, although not always (He et al., 2010; Geng et al., 2011), on soil nutrient availability (Mueller et al., 2010). For example, leaf N and P concentrations vary with geographical gradients in soil substrate and soil fertility (Reich & Oleksyn, 2004; Han et al., 2005; Townsend et al., 2007), and the leaf N/P ratio can be shifted by soil P availability in temperate rain forest in New Zealand (Richardson et al., 2008).

Precipitation and temperature can also affect leaf element concentrations by influencing element allocation among plant organs, by changing concentrations of elements associated with plant metabolism or by affecting vegetation species composition (Körner, 1989; Wright et al., 2001; Reich, 2005; Ordoñez et al., 2009). Several studies have found that leaf N and P concentrations are affected by latitude (Reich & Oleksyn, 2004; Han et al., 2005; Townsend et al., 2007) and climatic factors such as temperature and precipitation (Thompson et al., 1997; He et al., 2008). The latitudinal variations in leaf N and P concentrations are mainly shaped by mean annual temperature (Reich & Oleksyn, 2004). However, no latitudinal pattern of leaf N/P ratio has been found across biomes in China or in tropical rain forests of Central and South America (Han et al., 2005; Townsend et al., 2007).

Recent studies have shown that significant variations in plant nutrient concentrations can be explained by taxonomic affiliation (Thompson et al., 1997; Broadley et al., 2004; Willey & Fawcett, 2006). Some plant species can heavily accumulate certain elements (White et al., 2007). For example, plants in different angiosperm families and orders may accumulate significantly different concentrations of Ca, K and Mg in their shoots; eudicots generally have higher shoot Ca concentration than monocots, while commelinoid monocot species have lower shoot Ca concentration than other monocot species (Broadley et al., 2003, 2004; White & Broadway, 2003). Consequently, the species composition of vegetation communities could affect the geographical variation in leaf element concentrations. However, few studies have investigated the effects of phylogeny on leaf nutrients (Thompson et al., 1997; Broadley et al., 2004; Kerkhoff et al., 2006). Of these few studies, Kerkhoff et al. (2006) found significant phylogenetic signals in stem and leaf N and P concentrations of seed plants in natural vegetation, while Paoli (2006) found that within the tropical tree genus Shorea, the variation in N/P ratio is more strongly related to phylogeny than habitat, whereas leaf P is more related to habitat than phylogeny.

The balance of nutrients in plant tissues is of particular importance for plant growth (Ågren, 2008). Consequently, strong correlations among leaf elements have been observed from the individual plant to the global scale (Reich & Oleksyn, 2004; Ågren, 2008). Garten (1978) and Wright et al. (2005a) found that leaf N, P, Cu, sulphur (S) and Fe, which are related to the ‘nucleic acid–protein set’, are loaded on the first axis of a principal components analysis (PCA) of leaf element concentrations. Leaf Mg, Ca, K, Zn, Mn and N, which are associated with the ‘structural and photosynthetic set’, are loaded on the second axis, while leaf Mn, K and Mg, which are related to the ‘enzymatic set’, are loaded on the third axis. The strong interaction among leaf elements could possibly lead to the coordinated patterns of variation in N and P observed in leaves across plant species (Kerkhoff et al., 2006).

Global change would be likely to affect the spatial patterns in temperature and precipitation, and thus species composition, leading to changes in leaf element concentrations of plant community, and subsequently affecting nutrient cycling of ecosystems. Therefore, an understanding of these processes is important for modelling the nutrient cycling of ecosystems. In this study, the concentrations of 10 leaf elements of 702 terrestrial plant species from 66 families in 30 orders across terrestrial biomes in China were analysed using phylogenetically comparative methods and partial Mantel tests to determine the factors affecting their variation, especially to address how leaf nutrients are affected by environmental factors (latitude, precipitation and temperature) across China and how much an effect phylogeny has.

**MATERIALS AND METHODS**

The dataset presented in Appendix S1 in the supporting information was compiled from publications containing the concentrations (g kg⁻¹) of leaf K, Fe, Mn, sodium (Na), Ca, N, P, S, silica (SiO₂) and Al of 702 wild plant species from 91 sites covering almost all terrestrial vegetation types in China (Fig. 1). Data from planted specimens and polluted samples, and from plant families that contained many species but for which we found information for fewer than three species were excluded from the analyses. Latitude, altitude, mean annual temperature (MAT) and mean annual precipitation (MAP) were obtained directly from publications if the climatic data were available for the sampling sites (Appendix S1). Otherwise, the altitude and latitude of the geographical centre of the sampling area was obtained from Google Earth and MAT and MAP were taken from the nearest weather stations and corrected by an altitudinal lapse rate of 6 °C per 1000 m for MAT. The assignments to plant order and family were based on the Angiosperm Phylogeny Group III (APG III) classification (Angiosperm Phylogeny Group, 2009).

The phylogenetic affiliation of each taxon was incorporated into the analysis using the most recent consensus tree based on the APG III classification (Angiosperm Phylogeny Group, 2009). We built an angiosperm reference phylogeny that was resolved up to family level using the freely available software PHYLOMATIC (http://www.phylosphere.net/phylomatic/phylomatic.html). The Branch Length Adjuster (BLADJ) algorithm in
phylocom (Webb et al., 2008) in combination with estimated family ages (Wikström et al., 2001) was used to assign branch lengths to this phylogeny.

The data distributions of leaf element concentrations were assessed by a Shapiro–Wilk test prior to analysis of variance (ANOVA). Because this test showed that none of the leaf elements were distributed normally (Table 1), the original data were transformed by natural logarithm to generate the standardized leaf element concentrations. They were then analyzed by ANOVA (aov function) to test for differences in leaf element concentrations between taxonomical levels using the R statistical platform (version 2.10; R Development Core Team, 2010). The mean concentrations of leaf N, P, K and SiO2 were mapped on the family tree to identify their phylogenetic patterns.

A general linear mixed model was used to fit the variation components for each leaf element on the R statistical platform.
The possible evolutionary associations between latitude and leaf elements, and among leaf elements at family level, were assessed with the ‘analysis of traits’ module in PHYLCOM (Webb et al., 2008). This program calculates internal node values for continuous traits using the phylogenetic independent contrast (PIC) method (Felsenstein, 1985). Then the traditional Pearson correlation coefficients and PIC correlation coefficients were calculated by using the ‘lm’ function in the R package.

Partial Mantel tests were performed in the ‘ecodist’ package implemented in R 2.10 to evaluate the contribution of latitude, MAP and MAT to leaf nutrients. This method allows us to evaluate the pure effect of latitude on leaf nutrients by removing the MAT or MAP effect, and vice versa. The distance metrics of environmental variables and leaf nutrients were calculated by the Euclidean method in the ‘distance’ function of the ‘ecodist’ package. Then the partial Mantel correlation between the environmental matrices and leaf nutrient matrices was analysed by the ‘mantel’ function of the ‘ecodist’ package. Significant differences from zero in these coefficients were assessed by comparing reference distributions obtained after 999 iterations that randomly permuted the arrangement of the elements of one of the distance matrices.

A PCA was performed using the ‘prcomp’ function of the R package ‘vegan’ to characterize the associations of the 10 leaf elements at family level. To identify the environmental effect of the suits of the associated leaf elements, the correlations of the extracted vectors of each PCA axis with latitude, MAP and MAT were assessed by regression analysis (Wright et al., 2005b).

RESULTS

Taxonomic effects on leaf element concentrations

Leaf element concentrations varied considerably across species (Table 1). The magnitudes of variation in leaf macronutrients were generally smaller than those of micronutrients and non-essential elements. The variation in leaf N concentration among species was about 20-fold, in leaf P about 250-fold, and those in leaf K, S and Ca concentrations were 336- to 8182-fold, whereas species was about 20-fold, in leaf P about 250-fold, and those in essential elements. The variation in leaf N concentration among species were generally smaller than those of micronutrients and non-essential elements. The magnitudes of variation in leaf macronutrients were assessed by regression analysis (Wright et al., 2005b).

The relative importance of latitude and taxonomy on leaf element concentrations

Latitude explained 15.3–52.1% of total variation in leaf element concentration, while taxonomy explained 0.8–43.9% (Table 2). Latitude had a stronger effect on leaf N, P, K, Fe, Al, Mn, Na and Ca concentrations than taxonomy, while taxonomy had a stronger effect on leaf S and SiO2. However, latitudinal variation in leaf S and SiO2 concentrations still accounted for 15.3 and 20.5% of the total variation, respectively. The interaction of latitude with taxonomy had significant effects on leaf K, Al, Mn and Na concentrations, explaining more than 10% of total variation. For each leaf element, a large proportion (>17%) of total variation remained unexplained.

Both Pearson’s and PIC correlation analyses indicated that leaf N, P, K, S and Fe concentrations were correlated with latitude (Fig. 3). Pearson’s analysis found a significant correlation between leaf Na concentration and latitude, but this correlation disappeared after removing the phylogenetic effect. Although a weak correlation was found between leaf P and latitude when using Pearson’s and PIC correlation analyses, no correlation was found when using the partial Mantel test. Leaf N/P ratio, SiO2, Al, Mn and Ca did not show any latitudinal patterns at family level.

Climatic influences on leaf element concentrations

Mantel tests showed that latitude was correlated with leaf N, K, Fe, S and Na concentrations (Table 3). When controlled for MAP in the partial Mantel test, the significant correlation between latitude and leaf Na concentration disappeared, and the correlation between latitude and leaf Al concentration became significant. However, none of the correlations between leaf elements and latitude became insignificant when controlled for MAT.

Leaf N, S, Al, Fe and Na concentrations were correlated with MAP at family level, even when controlled for MAT (Table 4), whereas leaf P, K, SiO2, Mn, Ca concentrations were not correlated with MAP. Leaf N, P and Fe concentrations were correlated with MAT. However, these significant correlations disappeared after controlling for MAP (Table 4). Leaf K, S, SiO2, Al, Mn, Na and Ca were not correlated with MAT.

Correlations between leaf elements

Most leaf elements were positively correlated with each other, but leaf Mn concentration was negatively correlated with leaf N,
Figure 2 The phylogenetic distributions of leaf nitrogen (N), phosphorus (P), potassium (K) and silicon (SiO₂) concentrations (mean ± SE) at family level. The phylogeny is based on the Angiosperm Phylogeny Group III classification. The arrow indicates the evolutionary direction from primitive to advanced families.

Table 2 Partitioning of total variation (%) of each leaf element concentration into taxonomic and environmental (latitude) and residual components. The concentrations of all elements were transformed using natural logarithm prior to analysis.

<table>
<thead>
<tr>
<th>Variation sources</th>
<th>N (%)</th>
<th>P (%)</th>
<th>K (%)</th>
<th>S (%)</th>
<th>SiO₂ (%)</th>
<th>Fe (%)</th>
<th>Al (%)</th>
<th>Mn (%)</th>
<th>Na (%)</th>
<th>Ca (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>41.74</td>
<td>33.35</td>
<td>45.58</td>
<td>15.26</td>
<td>20.45</td>
<td>34.96</td>
<td>19.45</td>
<td>52.14</td>
<td>44.80</td>
<td></td>
</tr>
<tr>
<td>Taxonomy</td>
<td>4.88</td>
<td>5.78</td>
<td>10.22</td>
<td>43.85</td>
<td>40.18</td>
<td>0.81</td>
<td>12.08</td>
<td>13.84</td>
<td>21.67</td>
<td></td>
</tr>
<tr>
<td>Latitude x taxonomy</td>
<td>6.42</td>
<td>9.09</td>
<td>26.53</td>
<td>8.82</td>
<td>0.12</td>
<td>0.27</td>
<td>19.35</td>
<td>16.18</td>
<td>10.27</td>
<td>6.24</td>
</tr>
<tr>
<td>Residual</td>
<td>46.96</td>
<td>51.78</td>
<td>17.67</td>
<td>32.08</td>
<td>39.37</td>
<td>63.96</td>
<td>49.13</td>
<td>54.49</td>
<td>23.22</td>
<td>27.30</td>
</tr>
</tbody>
</table>
Several leaf elements, such as SiO₂, Al and Ca, were rarely correlated with other elements. When using the PIC method, leaf Ca and Al concentrations were not correlated with any other leaf elements, and the significant correlations of leaf N with Mn, Na and Fe disappeared, while the correlations between SiO₂ and Fe, and Fe and P became significant.

The correlation coefficients between the concentration of each of the 10 leaf elements and latitude assessed by partial Mantel test at family level are shown in Table 3. Leaf N, P, K, S, Na and Fe loaded mainly on the first PCA axis, explaining 29.1% of the total variation; leaf Ca and Al loaded on the second axis, explaining 17.0% of the total variation; and leaf Mn and SiO₂ loaded on the third axis, which explained 13.6% of the total variation (Table 5). The first axis of the PCA was also significantly correlated with latitude, MAT and MAP, while the second and third axes were not significantly correlated with the above three environmental variables.

### DISCUSSION

Several studies have found that leaf element concentrations vary with latitudinal and environmental gradients at a global or regional scale (Reich & Oleksyn, 2004; Han et al., 2005, 2011) and among taxonomic groups (Thompson et al., 1997; Broadley et al., 2001, 2004; Kerkhoff et al., 2006). However, the relative effects of taxonomy and environmental factors on leaf element concentrations have not yet been addressed. The analyses presented here provide new insight into the relationships between leaf element concentrations and taxonomy as well as the environment of terrestrial plants over a large geographical region.

### Taxonomic effect on leaf element concentrations

Our results showed that leaf element concentrations varied significantly across species and families (Table 1, Appendix S3), and that taxonomic variance accounted for up to 43.9% of this variation (Table 2). However, the proportion of the variance components attributable to taxonomy differed considerably between leaf elements. The taxonomic contribution to leaf S and
SiO₂ variation was significantly higher than the latitudinal contribution, while the contribution of latitude to leaf N, P, K, Al, Mn, Fe, Na and Ca concentrations was significantly larger than that of taxonomy. Previous studies have confirmed that leaf heavy metal concentrations, shoot mineral concentrations, and N, P and Mg concentrations in plant organs are constrained by taxonomic affiliations (Thompson et al., 1997; Broadley et al., 2001, 2004; Kerkhoff et al., 2006; Fyllas et al., 2009).

Some plant species can heavily accumulate certain elements (White et al., 2007). For example, Jansen et al. (2002) suggested that Al hyperaccumulators are particularly common in angiosperms such as rosids and asteroids. Hodson et al. (2005) found that the shoot SiO₂ concentration is influenced by the higher-level phylogenetic position of a plant. Our study found that ferns accumulate more SiO₂. The accumulation of SiO₂ is largely restricted to primitive land plants and certain monocot clades (Ma & Takahashi, 2002). Unlike gymnosperms and angiosperms, ferns lack strong mechanical tissues for support. Thus they employ a network of SiO₂ fibres to enhance mechanical support of frond weight by infilling SiO₂ to the cell walls and lumen of certain cells in plant tissues. Consequently, the variation in leaf element concentrations among taxonomic groups is likely linked to differences in structural or osmotic fractions of leaf tissues and selective uptake of certain nutrients by plants (White & Broadley, 2003; Watanabe et al., 2007; White et al., 2007).

### Environmental effects on leaf element concentrations

Leaf N, P, K, S, Fe and Na concentrations exhibited significant latitudinal patterns, while leaf Al, Mn, SiO₂, Ca and N/P ratio showed no latitudinal variation (Table 2, Fig. 3). Our study

<table>
<thead>
<tr>
<th>Component 1</th>
<th>Component 2</th>
<th>Component 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>0.759</td>
<td>-0.176</td>
</tr>
<tr>
<td>P</td>
<td>0.507</td>
<td>-0.270</td>
</tr>
<tr>
<td>K</td>
<td>0.815</td>
<td>0.047</td>
</tr>
<tr>
<td>S</td>
<td>0.598</td>
<td>0.401</td>
</tr>
<tr>
<td>SiO₂</td>
<td>0.220</td>
<td>0.244</td>
</tr>
<tr>
<td>Fe</td>
<td>0.745</td>
<td>0.349</td>
</tr>
<tr>
<td>Al</td>
<td>-0.225</td>
<td>0.697</td>
</tr>
<tr>
<td>Mn</td>
<td>-0.511</td>
<td>0.300</td>
</tr>
<tr>
<td>Na</td>
<td>0.655</td>
<td>0.210</td>
</tr>
<tr>
<td>Ca</td>
<td>0.226</td>
<td>-0.655</td>
</tr>
<tr>
<td>Total variation explained</td>
<td>29.1%</td>
<td>17.0%</td>
</tr>
<tr>
<td>Correlation (r) with environmental variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latitude</td>
<td>0.701***</td>
<td>0.091</td>
</tr>
<tr>
<td>MAT</td>
<td>0.525***</td>
<td>0.078</td>
</tr>
<tr>
<td>MAP</td>
<td>0.699***</td>
<td>0.008</td>
</tr>
</tbody>
</table>

MAT, mean annual temperature; MAP, mean annual precipitation.

***P < 0.001.
supports the previous finding that increasing leaf N and P concentrations are correlated with increasing latitude (Reich & Oleksyn, 2004; Han et al., 2005; Townsend et al., 2007), while it contradicts the report that leaf N and P concentrations are not related to latitude (Kerkhoff et al., 2005). The slope of the linear relationship between leaf N concentration and latitude in China was steeper than that at global scale (Reich & Oleksyn, 2004), indicating that latitudinal effects in China are stronger than in other regions. This could be due to the large variation in MAT with latitude in China, as the slope of the negative linear relationship between leaf N concentration and MAT in China was also steeper than that at global scale (Appendix S2). The correlations between latitude and leaf S, Na and Al concentration were driven by changes in MAP, not MAT (Table 3).

Leaf N, Fe, S, Al and Na concentrations decreased with MAP, while leaf N, P and Fe concentrations increased with MAT. Previous studies have suggested that leaf N and P concentrations are negatively associated with MAT at a global or regional scale (Reich & Oleksyn, 2004; Han et al., 2005; Fyllas et al., 2009), and leaf S, Na and K concentrations are negatively related to temperature and precipitation (Santiago et al., 2005). The correlations between MAP and leaf element concentrations did not change significantly when controlled for MAT. However, all correlations of MAT with leaf elements became insignificant when controlled for MAP (Table 4). This indicates that in China MAP has a stronger effect on leaf element concentrations than MAT.

Precipitation and temperature can either directly affect plant element concentrations by changing both the nutrient allocation among organs and the concentration of elements associated with metabolism, or indirectly by influencing the leaf N or P concentration via changing soil biogeographical processes and vegetation composition (Körner, 1989; Wright et al., 2001, 2005b; Reich, 2005; Ordoñez et al., 2009). For example, species with high leaf N and P concentrations usually have fast growth rates (Wright et al., 2001; Fyllas et al., 2009), therefore the variation in leaf elements can be linked to the physiological requirements of plants (Han et al., 2011). Meanwhile, N uptake and utilization by plants are also affected by soil temperature and water status (Dong et al., 2001). For example, a higher leaf concentration of macronutrients is an adaptive feature enhancing the metabolic activity of plants in cold habitats (Oleksyn et al., 2002).

Climatic factors also influence the species composition of plant communities, which in turn can affect the leaf element concentrations found in a community (Ordoñez et al., 2009), because root uptake ability for certain nutrients is different among species (Broadley et al., 2001). For example, the plant community assembly on acid soils is largely determined by the ability of plants to tolerate excessive Al, Mn and Fe, while that on the calcareous soils is determined by the ability of plants to tolerate Fe and P deficiencies (White & Broadley, 2003). Leaf Ca and Mn concentrations are profoundly influenced by soil acidity, and this effect interacts strongly with taxonomy (Thompson et al., 1997). In our study, leaf elements varied considerably across families (Fig. 2) and the interaction of taxonomy with latitude contributed considerably to this variation in leaf element concentrations (Table 2), indicating that the latitudinal variations in leaf element concentrations were related to taxonomy.

Soil nutrient availability is one of the main factors affecting the concentration of certain leaf elements (Broadley et al., 2001; Ordoñez et al., 2009). Tripler et al. (2006) suggested that tissue K concentration is affected by soil K availability around the world. However, He et al. (2010) found that soil total N concentration was not correlated with leaf N concentration in 171 species across Chinese grasslands. In our study, a large proportion of total variation in each leaf element remained unexplained. These unexplained variations could be related to soil nutrient availability. Unfortunately, soil nutrient data were not available for our sampling sites and we were unable to assess their correlation to leaf elements.

**Correlations of suites of associated leaf elements with the environment**

Many leaf elements, particularly N, P and K, were positively correlated with each other either with or without considering phylogeny (Appendix S4), indicating that they share correlated evolutionary changes. Leaf Al and Ca were not correlated with the other elements when using the PIC method, suggesting that they have evolved independently. The correlations among leaf elements can be linked to their biochemical function and chemical properties (Garten, 1976). Similar to the results of Garten (1978) and Wright et al. (2005a), we found that the first axis of the PCA largely represented variations in N, P, K, S, Fe and Na, the second axis represented those in Ca and Al, and the third axis represented those in Mn and SiO2 (Table 5). The elements associated with the first PCA axis were mainly involved in protein synthesis and photosynthesis. These leaf element concentrations were significantly affected by latitude, MAP and MAT. The other two PCA axes were associated with the leaf elements involved in cell structure and enzyme activity. These leaf element concentrations were not affected by latitude, MAP and MAT.

Leaf N/P ratio remained relatively constant across latitude in China. This result is consistent with the results of Han et al. (2005) from China and Townsend et al. (2007) around the world, but contradicts other studies that showed decreasing leaf N/P ratio with increasing latitude at global or regional scales (Reich & Oleksyn, 2004; Zheng & Shangguan, 2007). However, Chinese flora had a lower P concentration at a given leaf N concentration, which explained the higher N/P ratio in China compared with that on a global scale (Reich & Oleksyn, 2004) (Appendix S2). This is probably due to the low soil P concentration in China (Han et al., 2005) as the shift in leaf N/P ratio is linked to soil P (Richardson et al., 2008).

**CONCLUSIONS**

This study comprehensively characterized the relative effects of taxonomy and environmental factors on the latitudinal patterns of leaf K, S, SiO2, Fe, Al, Mn, Na and Ca concentrations in China. Leaf element concentrations were affected by the environment,
taxonomy and their interactions. But overall, the environment had a stronger effect than taxonomy on leaf element concentrations, with the exception of S and SiO₂. Therefore, changes in temperature and precipitation will directly affect the spatial patterns in leaf element concentrations via changes in vegetation composition and subsequently affect the associated ecosystem nutrient fluxes and functioning.

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REFERENCES


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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Leaf element concentrations and environmental variables of 702 plant species.

Appendix S2 Comparison of bivariate relationships between leaf elements and environmental variables of Chinese terrestrial plants with a global dataset.

Appendix S3 Leaf element concentrations of 66 plant families in China.

Appendix S4 Correlations among leaf elements at family level.

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BIOSKETCHES

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