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Response of Leaf Functional Traits of Landscape Plants to Urban Green Space Environment in Lanzhou, China

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Abstract: Leaf functional traits are the essential components of adaption plant strategies and have different responses to various environments, but our knowledge of how plants adapt to highly complex urban environments through coordinated changes in leaf functional traits is limited. In this study, we studied the response of landscape plants to the environments of sports field (SF), park (PAR), residential green space (RES), and greenway (GW), and analyzed the effects of the different green space environments on trade-off strategies of plants based on leaf functional traits. The results showed that leaf functional traits of plants and adaptation strategies varied among different urban environments in Lanzhou, China. Leaf length (LL), width (LW), area (LA), and special leaf area (SLA) were PAR > SF > RES > GW. Leaf nitrogen (LNC) and phosphorus content (LPC) were SF > PAR > RES > GW. Leaf carbon content (LCC), leaf dry matter content (LDMC), the ratio of leaf carbon and nitrogen (C/N), and the ratio of leaf carbon and phosphorus (C/P) was GW > RES > PAR > SF. The landscape plants in SF and PAR were more adaptive to the urban environment than those in RES and GW. Among different green space environments, landscape plants in SF and PAR tended to have an acquisitive strategy with high LL, LW, LA, SLA, LNC, and LPC. In contrast, plants in RES and GW tended to have a conservative strategy with a high level of concentration of LCC, LDMC, C/N, and C/P.

Keywords: leaf morphological traits; leaf nutrients traits; landscape plants; urban green space environment; adaptation strategy



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1. Introduction

With the rapid economic development and population growth, urbanization is rising [1]. It significantly affects cities' physical environment, biotic components, and ecosystem processes [2]. It is one of the current environmental challenges in many cities worldwide [3]. Although urbanization improves living standards and convenience, it creates severe ecological problems, such as air pollution, urban heat islands, soil degradation, and biodiversity loss [1].

Urban green space is one of the critical sections in cities under urbanization for environmental protection. It refers to any green spaces, including the permeable hard-surface areas, mainly consisting of "soft surfaces", such as vegetation and soil [4]. Urban green space exists in a broad variety, such as sport fields, parks, residential green spaces, city farms, greenways, private green areas, and agricultural areas [5]. It is ecological land dominated by natural and artificial vegetation in cities, plays a particular role in the structure of the urban regions [6], and adjusts the urban climate and improves human settlements by affecting the energy and water exchange between the near-surface atmosphere and the underlying surface [7]. Owing to the most critical part of the urban construction and inlaid distribution with human settlements, urban green spaces have become some of the most

intimate interfaces between humans and the environment. It is the basis of human health and happiness [8,9]. The vegetation of urban green spaces determines the capacity of the urban environment to support biodiversity. It is the component most easily manipulated by humans through interference and direct management actions [10]. Urban landscape plants can provide ecosystem services directly or indirectly, such as carbon fixation and the release of oxygen, cooling and humidifying, pollution removal, and food provision [11].

Plant functional traits refer to a series of plant features correlated to their ability to acquire, utilize, and preserve resources [12] and can be used to provide species selection in urban greening [13]. They mediate plants' response to the environment and can be defined as the characteristics of plants relevant to their response to the environment and its effects on ecosystem functioning [2,14]. In general, plant functional traits can be categorized into four groups, including whole-plant characteristics, stem and belowground traits, regenerative traits, and leaf functional traits [15]. Leaf functional traits are essential characteristics of plants, directly affecting plants' basic morphology and function [16] and are always used to detect environmental changes [17,18]. They vary in response to different environments and are considered to be parameters of prime importance in response of plant species to their environments [19,20]. Variation of leaf functional traits has been found to indicate a trade-off between a resource-acquisition strategy and a resource-conservation strategy [21]. For example, plants adopting acquisitive strategies tend to present higher specific leaf area (SLA) and leaf nitrogen content (LNC) and lower leaf dry matter content (LDMC), since they invest in traits capable of assuring greater resource acquisition [22]. The trade-off and correlation between these leaf functional characteristics show the adaptation of plants to the environment [23]. Therefore, studying the changes in leaf functional traits and their relationships will help understand plant adaptation strategies [24]. It is of substantial significance to study leaf functional traits in combination with the environment and individual plants to reveal the responses of plants to different environments [25]. It has generally become a critical topic that many ecologists use to study the adaptability of plants to the environment [26,27].

Environmental changes will often be mediated by choosing plants with certain traits that improve plant competition, resistance, or resource conservation [1]. The urban green space environment is complex and changeable because of high-intensity disturbance [28]. Plants growing in an urban environment will adopt trade-off strategies to better adapt to the environment. Previous studies have shown that each green space's property is separate, owing to different management practices and surroundings. This difference affects the expression of plant functional traits [29–31]. The types of urban green space are different due to geography, socioeconomics, environment, and function [4]. Different types of green space have different impacts on plant growth. Nevertheless, the research on plant leaf functional traits in cities is currently more focused on seedlings or manually controlled experiments in greenhouses, which cannot accurately reflect the characteristics of the urban environment [32]. Some researchers concentrate on the change of plant functional traits to the environment under urban–rural gradients [33,34], but how plants respond to different environments within cities under urbanization is unclear.

In this study, we selected eight landscape plants in four green space environments (sports field, park, residential green space, and greenway) in Lanzhou, a city in northwest China. Eleven functional traits of eight plants in four green spaces were measured. The purpose of this study was to (1) examine the effects of different green space environments on leaf functional traits; and (2) discuss the trade-off strategies between leaf functional traits of eight landscape plants in different green space environments. Our hypothesis was that (1) leaf functional traits of eight plants vary in different green space environments; and (2) plants adapt to the different environments via synergistic changes among leaf functional traits.

2. Materials and Methods

2.1. Study Site and Plants Selection

The study site was located in Lanzhou (102°36′~104°35′ E; 35°34′~37°00′ N), which is a northwest city of China and the capital and political, economic, and cultural center of Gansu Province. It belongs to a temperate continental climate with an annual average temperature of 9.8 °C [35]. The average elevation of the urban area is 1520 m. The annual average precipitation is 327 mm, with over 60% falling from June to September. The average frost-free period is 185~200 d, and annual relative humidity is 58%. This area is characterized by gray calcareous soil [36].

According to the 2020 Lanzhou statistical yearbook [37], the built-up area of Lanzhou covered 343.12 km² in 2019; the population was 2.57 million, accounting for 67% of the total population of Lanzhou; the urban green space area reached 100.04 km². The ratio of green space to built-up areas had reached 29.16%. The urban green space in built-up area is the most important to the environment of Lanzhou city. After field investigations and consulting relevant experts and management units [38], we chose four main green space types of Lanzhou built-up area, divided based on Panduro et al. [39] and Nor et al. [4], namely, sport field (SF), park (PAR), residential green space (RES), and greenway (GW) (Figure 1 and Table 1).

Many plants have been planted in various green spaces in the built-up areas of Lanzhou. Trees and shrubs dominate the greening plants, followed by herbs. Eight landscape plants were chosen in each green space, which were *Cedrus deodara* (Roxb. ex Lamb.) G. Don, *Picea asperata* Mast, *Euonymus maackii* Rupr, *Prunus cerasifera* f. *atropurpurea* (Jacq.) Rehd, *Fraxinus chinensis* Roxb, *Prunus triloba* (Lindl.) Ricker, *Forsythia suspensa* (Thunb.) Vahl, and *Euonymus japonicus* Thunb. We considered plants based on the following factors: (1) Distribution: in four green spaces, eight plants all occur; (2) dominance: the plants were the dominant species in urban green space; (3) life forms: the species contained evergreen, deciduous, tree and shrub [40]. The selected individuals within a species had similar height, canopy diameter, and diameter at breast (Table 2).

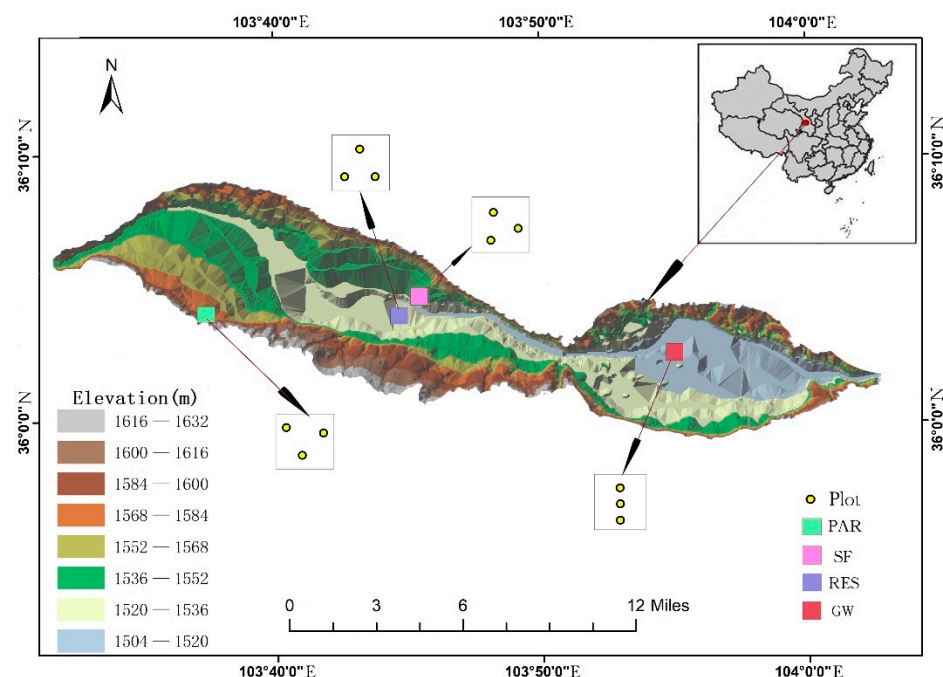


Figure 1. Distribution of sampling sites and plots in built-up area of Lanzhou city.

Table 1. Description and basis condition of each type of urban green space.

Type	Definition	Condition of Fertilization		Condition of Irrigation		Condition of Pesticide Use	Disturbance	Condition of Pruning
		Frequency	Fertilizer	Frequency	Water			
Sport field (SF)	This green space is located at schools or institutions, which provide a place for rest and entertainment for staff members or students. These areas often form a square and are outlined by trees.	Three times a year	Organic compound fertilizer	Once every 2 to 3 days	Tap water	Six times a year	0~50 people pass through the green space every day	No pruning for all trees; Once a year for shrubs
Park (PAR)	This green space is open to the public, with recreation as its primary function. The maintenance is high, and the vegetation is well-kept. There are footpaths and service facilities in the green area, through which people can enjoy different features and exercise.	Three times a year	Organic compound fertilizer	Once every 2 to 3 days	Tap water	Six times a year	More than 500 people pass through the green space every day	
Residential green space (RES)	This green space is a small park planted with shrubs and trees, equipped with a playground, and located in a residential area. Children and adults always use it.	Once a year	Organic compound fertilizer	Once every 4 to 5 days	Tap water	Four times a year	More than 300 people pass through the green space every day	
Greenway (GW)	Greenway is an area of vegetation along a major urban road, which serves to buffer people from traffic, screen noise and solar radiation. It is designed to increase the area of urban green space and improve the urban environment.	Once a year	Organic compound fertilizer	Three times a year for trees; once a month for shrub	Tap water	Four times a year	More than 500 people and 500 vehicles pass through the green space every day	

Table 2. Growth indicators of eight landscape plants.

Trees	Family	Genera	Breast Diameter/cm	Height/m	Canopy Diameter/m	Life Type
<i>Cedrus deodara</i> (Roxb. ex Lamb.) G. Don	Pinaceae	Cedrus	11.9~13.7	8.9~12.3	5.9~7.4	Evergreen tree
<i>Picea asperata</i> Mast	Pinaceae	Picea	9.0~11.7	5.0~7.4	3.5~5.3	Evergreen tree
<i>Euonymus meackii</i> Rupr	Celastraceae	Euonymus	9.7~11.0	6.4~7.1	4.2~5.8	Deciduous tree
<i>Prunus cerasifera</i> f. <i>atropurp-urea</i> (Jacq.) Rehd	Rosaceae	Prunus	10.7~12.7	5.6~5.9	2.8~3.5	Deciduous tree
<i>Fraxinus chinensis</i> Roxb	Oleaceae	Fraxinus	12.8~14.9	7.3~8.6	4.9~5.2	Deciduous tree
<i>Prunus triloba</i> (Lindl.) Ricker	Rosaceae	Prunus	/	2.4~2.6	2.6~3.1	Deciduous shrub
<i>Forsythia suspensa</i> (Thunb.) Vahl	Oleaceae	Forsythia	/	2.6~3.2	2.5~2.8	Deciduous shrub
<i>Euonymus japonicus</i> Thunb.	Celastraceae	Euonymus	/	1.0~1.3	1.1~1.4	Evergreen shrub

2.2. Field Sampling

In SF, PAR, RES, and GW, we selected a total of 12 plots, meaning that there were three plots in each green space type (Figure 1). In each plot, complete leaves on three mature and healthy individuals of each species were selected randomly from each plot, fully exposed to sunlight and lacking diseases or pests [40]. Three trees of each species in each plot were pooled to obtain a composite sample [41]. The samples were collected at the same location on the same day. We all chose 288 trees and collected a total of 96 samples of eight plants in four green spaces.

In September 2020, to minimize errors owing to the diurnal variation of specific leaf areas between morning and afternoon [42], the leaves were collected from 8:30~11:00.

Twenty gram samples were taken from each tree (5 g from the four different azimuth orientations) in the upper third of the crown (current-year leaves were sampled for evergreen species). Branch shears were used to collect the leaves and all samples were taken with branches [15]. The leaves were wrapped in moist paper and placed in sealed polyethylene bags. All samples were stored in a refrigerated box during transport to the laboratory. Samples over 24 h were held at 2~6 °C [42]. Figure 2 showed the whole process of the experiment.

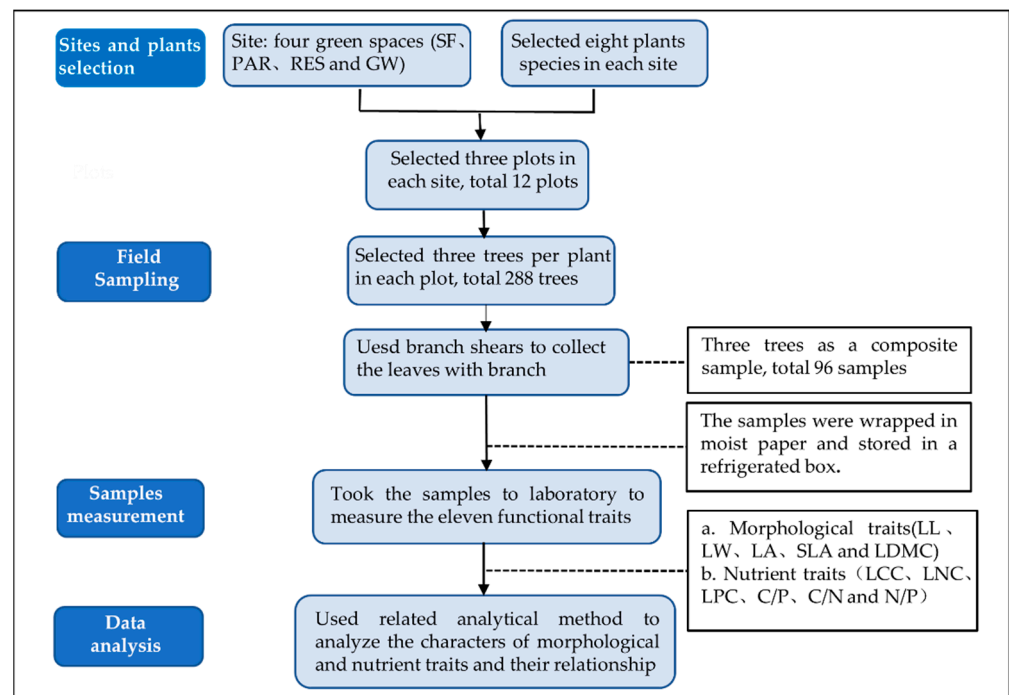


Figure 2. The flowchart of experimental method.

2.3. Measurements of Leaf Functional Traits

We chose eleven leaf functional traits, leaf area (LA), leaf length (LL), leaf width (LW), specific leaf area (SLA), leaf dry matter content (LDMC), leaf carbon content (LCC), leaf nitrogen content (LNC), leaf phosphorus content (LPC), leaf carbon/nitrogen ratio (C/N), leaf carbon/phosphorus ratio (C/P), and leaf nitrogen/phosphorus ratio (N/P). These leaf functional traits play an important role in plant growth and development, which are the most common and significant features of plants. They are also very sensitive to environmental changes, especially in urban environments [1,40,43].

Ten leaves of broad-leaved plants and twenty leaves of coniferous plants in each plot were chosen randomly to measure morphological traits. LA, LL, and LW of broad-leaved plants were measured by AM350 portable leaf area meter (ADC Bioscientific). LL, LW, and LA of coniferous plants were measured following the methods described by Liu [44]. Then, all leaves were numbered and immersed in water and maintained in the dark for 12 h at 5 °C to rehydrate. The leaves were gently blotted dry with tissue paper to remove surface water and weighed on a 1/10,000 electronic balance (water-saturated fresh weight) [41]. Then, they were dried at 70 °C until constant weight and weighed again (dry weight). SLA is determined as the ratio of leaf area to leaf dry weight. LDMC is determined as the ratio of leaf dry weight to water-saturated fresh weight [41,42].

Some samples were dried at 70 °C until constant weight and then grounded and passed through a 100 mesh sieve to analyze elements [45]. LCC, LNC, and LPC were measured using the potassium dichromate method, modified Kjeldahl method, and molybdenum anticolorimetric method, respectively [1,46].

2.4. Data Analysis

Two-way analysis of variance was performed to assess the effects of environment, plant, and the environment \times plant interaction on leaf functional traits. One-way analysis of variance (ANOVA) and LSD multiple comparisons were used to test the significance of the differences in leaf functional traits among four green space environments. Pearson correlation analysis and linear regression were used to explore the relationship of the functional traits among four green spaces. All the data were analyzed using SPSS 19.0 (IBM, Inc., Armonk, NY, USA), and the figures were drawn using Origin 2019 (OriginLab, Northampton, MA, USA).

The coefficient of variation (CV) = standard deviation of traits \times 100/mean value of traits.

The plasticity index (PI) = (MIX – MIN)/MIN, where MIX and MIN represent the maximum and minimum of the mean values of the four green space environments, respectively [47].

3. Results

3.1. The Sensitivity of Landscape Plants to the Different Environments

As shown in Table 3, environments have significant effects on the LW, SLA, LDMC, LCC, LNC, LPC, C/N, C/P, and N/P ($p < 0.001$), and significant effects on the LA ($p < 0.01$). Plants have significant effects on the LA, LL, LW, SLA, LDMC, LCC, LNC, LPC, C/N, C/P, and N/P ($p < 0.001$), and significant effects on the LL ($p < 0.01$). Environment \times plants have significant impact significant effects on the LCC, LNC, LPC, C/N, C/P, and N/P ($p < 0.001$), and significant effects on the LDMC ($p < 0.05$). These results indicated that environments and plants affected leaf morphology and leaf nutrient traits extremely significantly. Environment \times plants interaction had more effect on leaf nutrient traits than leaf morphology traits. These results also indicated that the four green space environments had different leaf functional traits due to different green space environments.

Table 3. Effects of the urban green space environment, plants, and interaction on leaf functional traits.

		LA	LL	LW	SLA	LDMC	LCC	LNC	LPC	C/N	C/P	N/P
Environment	F	5.40	0.51	7.13	19.94	35.85	141.67	226.86	68.44	546.20	394.53	15.04
	P	0.002	0.677	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Plants	F	60.48	28.93	138.21	16.49	62.22	18.56	257.60	25.72	124.26	51.68	34.92
	P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Environment \times Plants	F	0.81	1.34	1.42	0.94	2.13	13.08	21.42	5.87	19.88	20.05	11.47
	P	0.700	0.183	0.141	0.549	0.011	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

LA = leaf area; LL = leaf length; LW = leaf width; SLA = specific leaf area; LDMC = leaf dry matter content; LCC = leaf carbon content; LNC = leaf nitrogen content; LPC = leaf phosphorus content; C/N = leaf carbon/nitrogen ratio; C/P = leaf carbon/phosphorus ratio; N/P = leaf nitrogen/phosphorus ratio.

3.2. Differences of Leaf Functional Traits of Eight Landscape Plants in the Urban Green Space Environment

3.2.1. Leaf Morphological Traits in the Different Green Space Environment

As shown in Figure 3, except for *P. asperata*, LA, LL, LW, and SLA of *C. deodara*, *E. maackii*, *P. cerasifera*, *F. chinensis*, *P. triloba*, *F. suspensa*, and *E. japonicus* in SF and PAR were higher than those in RES and GW. In contrast, LDMC of all plants in RES and GW was higher than those in SF and PAR. LA of *C. deodara* and *F. suspensa* was the highest in SF, and significantly different from PAR, RES, and GW ($p < 0.05$). LA of *P. asperata* and *P. cerasifera* was the highest in PAR, and significantly different from SF, RES, and GW ($p < 0.05$). LL of *C. deodara*, *F. chinensis*, *F. suspensa*, and *E. japonicus* was the highest in SF, and not significantly different from those in PAR, but significantly different from those in RES and GW ($p < 0.05$). In PAR, LL of *E. maackii*, *P. cerasifera*, and *P. triloba* were significantly higher than those in RES and GW ($p < 0.05$), but not significantly different from SF ($p > 0.05$). LL of *P. asperata* in PAR was significantly different among SF, RES, and GW. With the exception of *C. deodara* and *F. suspensa*, LW of *P. asperata*, *E. maackii*,

P. cerasifera, *F. chinensis*, *P. triloba*, and *E. japonicus* was the highest in PAR, and LW of *P. asperata*, *E. maackii*, and *P. cerasifera* in PAR was significantly different from SF, RES, and GW ($p < 0.05$). In PAR, the SLA of *P. cerasifera*, *F. chinensis*, *P. triloba*, and *F. suspensa* was significantly higher than SF, RES, and GW ($p < 0.05$). In GW, LDMC of *C. deodara*, *P. asperata*, *E. maackii*, *P. cerasifera*, *F. chinensis*, *P. triloba*, *F. suspensa*, and *E. japonicus* was the highest. LDMC of *P. asperata*, *E. maackii*, and *F. suspensa* in GW was not significantly different from RES, but was significantly different from SF and PAR ($p < 0.05$).

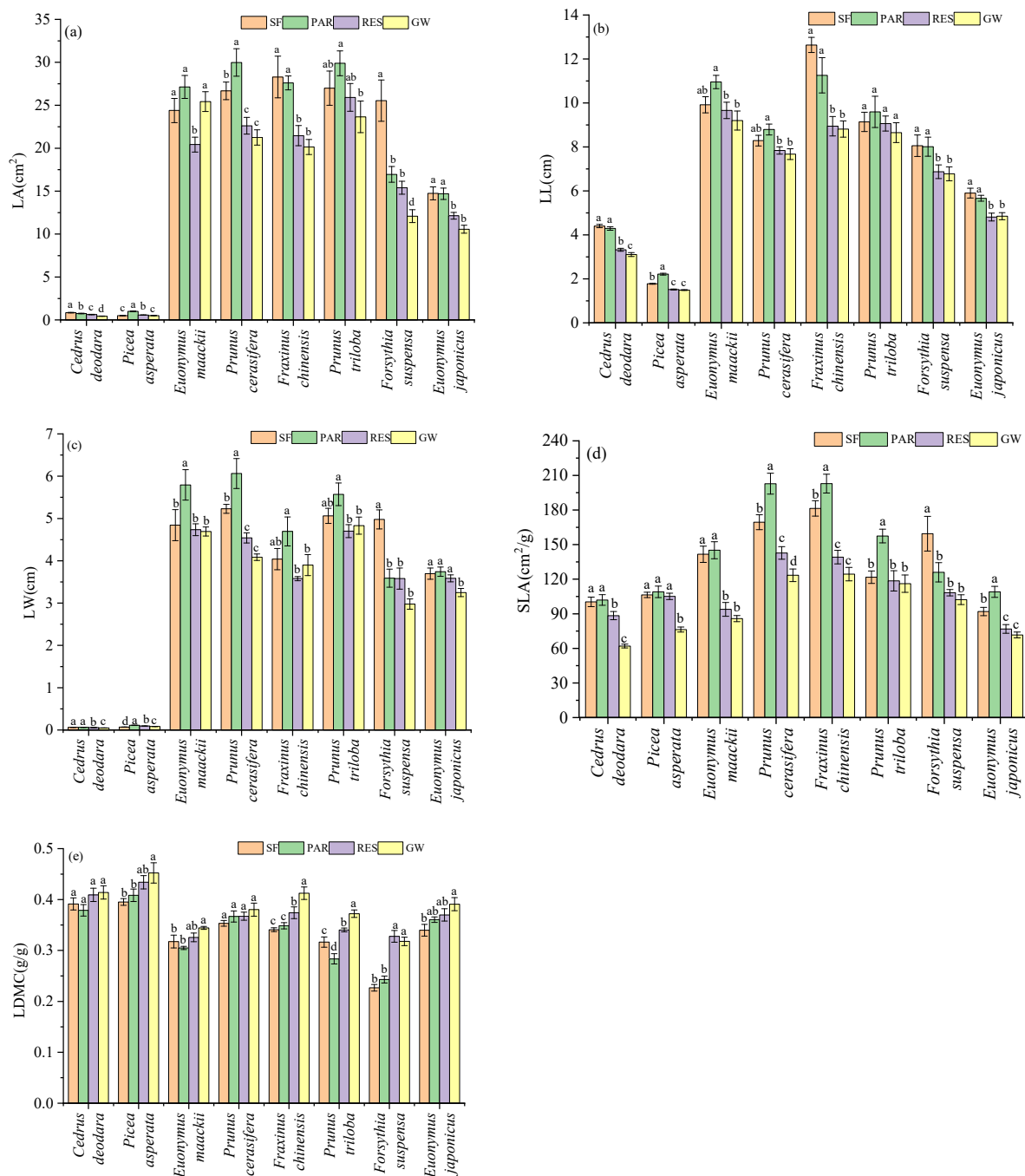


Figure 3. Characteristics of the leaf morphological traits of eight plants in four urban green space environments. SF = sport field; PAR = park; RES = residential green space; GW = greenway. Different letters above the bars indicate significant differences among four urban green spaces: (a) leaf area (LA); (b) leaf length (LL); (c) leaf width (LW); (d) specific leaf area (SLA); (e) leaf dry matter content (LDMC).

3.2.2. Leaf Nutrient and Stoichiometric Traits in Different Green Space Environments

As shown in Figure 4, the LCC of eight plants in GW was the highest. LCC of *C. deodara* and *E. maackii* was significantly different among four green spaces ($p < 0.05$). LNC of *C. deodara*, *F. suspensa*, and *E. japonicus* in SF was significantly higher than that of PAR, RES, and GW ($p < 0.05$). LNC of *E. maackii* in SF was not significantly higher than that of RAR and RES ($p > 0.05$), but significantly higher than GW ($p < 0.05$). LNC of *P. asperata* and *P. triloba* in PAR was the highest and was significantly different from SF, RES, and GW ($p < 0.05$). LNC of *P. cerasifera* and *F. chinensis* was significantly higher than GW ($p < 0.05$) but not significantly different from SF and RES ($p > 0.05$). In SF, PAR, and RES, LPCs of *C. deodara* and *P. asperata* were not significantly different from each other ($p > 0.05$) but were significantly higher than GW ($p < 0.05$). LPC of *E. maackii*, *F. chinensis*, *P. triloba*, and *E. japonicus* in SF and PAR was significantly higher than RES and GW ($p < 0.05$). C/N of all plants in GW was significantly higher than that of RES, PAR, and SF ($p < 0.05$). C/P of *C. deodara*, *P. asperata*, *P. cerasifera*, *F. chinensis*, *P. triloba*, and *F. suspensa* in GW was significantly higher than that of SF, PAR, and RES ($p < 0.05$). C/P of *E. japonicus* in RES was significantly higher than SF, PAR, and GW ($p < 0.05$). N/P of *C. deodara* and *P. cerasifera* in SF was the highest. N/P of *E. maackii*, *P. triloba*, *F. suspensa*, and *E. japonicus* in RES was the highest; the values were 7.37, 9.10, 9.24, and 5.29. N/P of *P. asperata* and *F. chinensis* in GW was the highest; the values were 8.88 and 8.56. In addition, most of the LNC and LPC of evergreen trees (*C. deodara*, *P. asperata*, and *E. japonicus*) in four green spaces were lower than deciduous plants.

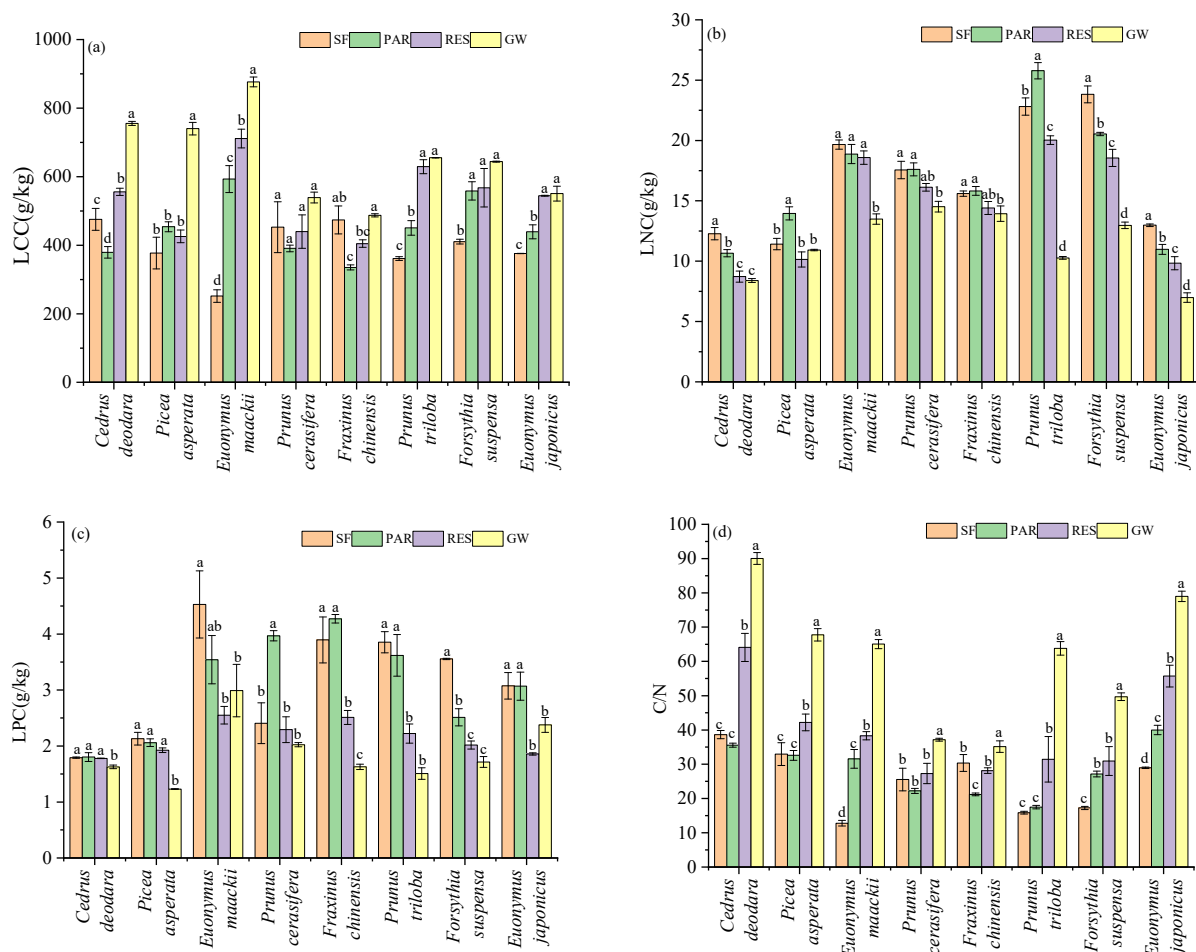


Figure 4. Cont.

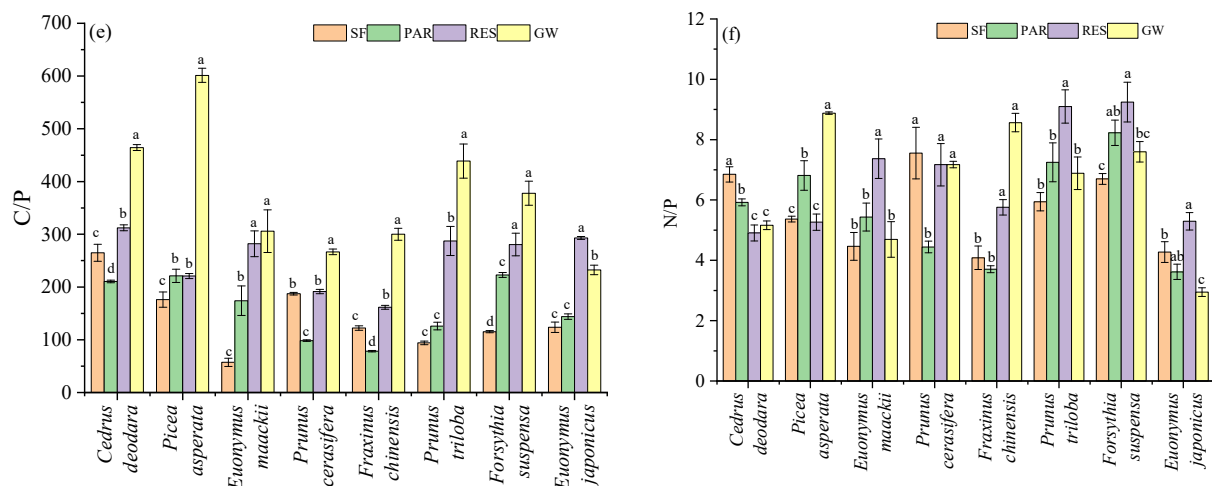


Figure 4. Characteristics of the leaf nutrient traits of eight plants in four urban green space environments. SF = sport field; PAR = park; RES = residential green space; GW = greenway. Different letters above the bars indicate significant differences among four urban green spaces: (a) leaf carbon content (LCC); (b) leaf nitrogen content (LNC); (c) leaf phosphorus content (LPC); (d) leaf carbon/nitrogen ratio(C/N); (e) leaf carbon/phosphorus ratio (C/P); (f) leaf nitrogen/phosphorus ratio(N/P).

3.2.3. Coefficient of Variation and Plasticity Index of Leaf Morphology and Leaf Nutrient Traits of Eight Landscape Plants in Four Green Space Environments

The coefficient of variation (CV) and plasticity index (PI) are two important indicators that reflect the conservation and heritability of traits in the evolutionary process. The larger the value of the two indicators, the stronger the adaptability of plants to the environment [48]. As shown in Table 4, the CV and PI of leaf morphological traits of eight landscape plants were greater than those of leaf nutrient traits. The mean values of CV and PI of leaf morphological traits were PAR > SF > GW > RES. The mean values of CV and PI of leaf nutrient traits were SF > RES > PAR > GW.

Table 4. Coefficient of variation and plasticity index of leaf morphology and leaf nutrient traits of eight garden plants in four green space environments. SF = sport field; PAR = park; RES = residential green space; GW = greenway.

Traits	Species	Coefficient of Variation (CV/%)				Plasticity Index (PI)			
		SF	PAR	RES	GW	SF	PAR	RES	GW
Leaf morphology	<i>Cedrus deodara</i>	25.106	25.941	25.088	23.422	0.674	0.722	0.656	0.623
	<i>Picea asperata</i>	14.636	26.488	16.092	17.713	0.474	0.732	0.534	0.539
	<i>Euonymus maackii</i>	28.461	21.913	22.002	16.893	0.678	0.524	0.615	0.439
	<i>Prunus cerasifera</i>	15.546	23.391	16.500	18.657	0.461	0.559	0.466	0.562
	<i>Fraxinus chinensis</i>	24.425	25.348	20.869	24.594	0.547	0.604	0.575	0.659
	<i>Prunus triloba</i>	25.519	26.646	23.776	28.065	0.637	0.650	0.590	0.658
	<i>Forsythia suspensa</i>	35.341	28.756	24.539	23.883	0.743	0.678	0.632	0.626
	<i>Euonymus japonicus</i>	21.744	17.148	19.020	19.171	0.639	0.526	0.543	0.561
	Mean	23.847	24.454	20.986	21.550	0.607	0.624	0.576	0.583
Leaf nutrient	<i>Cedrus deodara</i>	7.060	4.716	6.054	3.043	0.125	0.083	0.107	0.057
	<i>Picea asperata</i>	12.024	7.988	7.448	2.536	0.197	0.140	0.133	0.046
	<i>Euonymus maackii</i>	15.233	16.265	9.717	13.945	0.247	0.262	0.171	0.226
	<i>Prunus cerasifera</i>	17.649	4.880	13.287	3.590	0.284	0.091	0.224	0.066
	<i>Fraxinus chinensis</i>	12.040	3.656	6.059	5.903	0.207	0.068	0.112	0.107
	<i>Prunus triloba</i>	6.026	10.172	8.854	7.029	0.109	0.175	0.155	0.117
	<i>Forsythia suspensa</i>	3.580	6.892	12.396	5.944	0.064	0.122	0.222	0.103
	<i>Euonymus japonicus</i>	7.936	8.335	4.418	6.949	0.138	0.150	0.081	0.127
	Mean	10.193	7.863	8.529	6.117	0.171	0.136	0.151	0.106

3.2.4. The Relationship of Leaf Morphological and Leaf Nutrient Traits in Different Green Space Environments

As shown in Table 5, LA, LL, LW, and SLA were positively correlated with each other, and they were also negatively correlated with C/N and C/P in four green spaces. With the exception of LDMC and LCC and LDMC and LPC in SF, LDMC was negatively correlated with LA, LL, LW, SLA, LNC, LPC, and N/P and positively correlated with C/N in four green spaces. LCC was negatively correlated with LA, LL, LW, and LNC in SF and GW, but positively correlated with that in PAR and RES. LCC was negatively correlated with LPC in SF and PAR, but positively correlated with LPC in RES and GW. LNC was positively correlated with LPC and N/P, but negatively correlated with C/N and C/P. LPC was negatively correlated with C/P. C/N was positively correlated with C/P, but negatively correlated with N/P. C/P was positively correlated with N/P.

Table 5. Pearson correlation of morphological traits and leaf nutrient traits of eight landscape plants among four green space environments. SF, sport field; PAR, park; RES, residential green space; GW, greenway. LL, leaf length; LW, leaf width; LA, leaf area; SLA, specific leaf area; LDMC, leaf dry matter content. LCC, leaf carbon content; LNC, leaf nitrogen content; LPC, leaf phosphorus content; C/N, leaf carbon/nitrogen ratio; C/P, leaf carbon/phosphorus ratio; N/P, leaf nitrogen/phosphorus ratio. * Represents $p < 0.05$; ** represents $p < 0.01$.

		LA	LL	LW	SLA	LDMC	LCC	LNC	LPC	C/N	C/P
LL	SF	0.794 **									
	PAR	0.808 **									
	RES	0.802 **									
	GW	0.670 **									
LW	SF	0.848 **	0.721 **								
	PAR	0.937 **	0.697 **								
	RES	0.914 **	0.843 **								
	GW	0.877 **	0.761 **								
SLA	SF	0.709 **	0.681 **	0.579 **							
	PAR	0.778 **	0.620 **	0.632 **							
	RES	0.423 *	0.185	0.290							
	GW	0.645 **	0.335	0.546 **							
LDMC	SF	−0.561 **	−0.348	−0.599 **	−0.257						
	PAR	−0.477 *	−0.504 *	−0.470 *	−0.081						
	RES	−0.687 **	−0.699 **	−0.792 **	−0.045						
	GW	−0.478 *	−0.439 *	−0.533 **	−0.241						
LCC	SF	−0.131	−0.039	−0.205	0.132	0.171					
	PAR	0.090	0.147	0.189	−0.286	−0.568 **					
	RES	0.178	0.292	0.337	−0.401	−0.578 **					
	GW	−0.140	−0.320	−0.255	−0.455 *	−0.094					
LNC	SF	0.654 **	0.527 **	0.728 **	0.326	−0.789 **	−0.184				
	PAR	0.668 **	0.514 *	0.607 **	0.383	−0.738 **	0.388				
	RES	0.781 **	0.583 **	0.759 **	0.331	−0.762 **	0.404 *				
	GW	0.557 **	0.088	0.438 *	0.568 **	−0.293	−0.071				
LPC	SF	0.560 **	0.702 **	0.597 **	0.260	−0.514 *	−0.275	0.623 **			
	PAR	0.874 **	0.772 **	0.772 **	0.762 **	−0.218	−0.142	0.433 *			
	RES	0.545 **	0.578 **	0.536 **	0.409 *	−0.477 *	0.168	0.549 **			
	GW	0.444 *	0.545 **	0.478 *	−0.081	−0.428 *	0.276	0.138			
C/N	SF	−0.621 **	−0.472 *	−0.722 **	−0.240	0.662 **	0.697 **	−0.815 **	−0.627 **		
	PAR	−0.671 **	−0.506 *	−0.536 **	−0.689 **	0.387	0.238	−0.766 **	−0.590 **		
	RES	−0.698 **	−0.401	−0.586 **	−0.600 **	0.432 *	0.234	−0.771 **	−0.535 **		
	GW	−0.554 **	−0.244	−0.527 **	−0.732 **	0.208	0.545 **	−0.861 **	0.054		
C/P	SF	−0.571 **	−0.550 **	−0.658 **	−0.199	0.568 **	0.622 **	−0.587 **	−0.849 **	0.815 **	
	PAR	−0.720 **	−0.575 **	−0.621 **	−0.744 **	−0.044	0.528 **	−0.201	−0.900 **	0.562 **	
	RES	−0.212	−0.104	−0.071	−0.629 **	−0.187	0.765 **	−0.044	−0.494 *	0.677 **	
	GW	−0.551 **	−0.761 **	−0.681 **	−0.283	0.431 *	0.447 *	−0.211	−0.700 **	0.316	
N/P	SF	−0.025	−0.252	−0.024	0.067	−0.069	0.145	0.192	−0.599 **	−0.029	0.527 **
	PAR	−0.251	−0.284	−0.216	−0.369	−0.468 *	0.456 *	0.482 *	−0.561 **	−0.174	0.686 **
	RES	0.638 **	0.368	0.605 **	0.174	−0.632 **	0.333	0.877 **	0.087	−0.647 **	0.184
	GW	−0.009	−0.427 *	−0.140	0.412 *	0.237	−0.211	0.566 **	−0.698 **	−0.613 **	0.506 *

We selected indicators with significant correlation among four green spaces for linear regression ($p < 0.05$ or $p < 0.001$) (Figure 5). The slopes of linear regression of LA and LW, LA and LDMC, and LW and LDMC were the same among four green spaces. The slopes of linear regression of LA and LPC, LA and SLA, and LW and LPC in PAR were the largest. The slopes of linear regression of LW and LNC, and LL and LW in RES were the largest. The slopes of linear regression of LA and LNC, LA and C/N, LW and C/N, LNC and C/N, and LPC and C/P in GW were the largest. It showed that there was a co-evolutionary and

trade-off relationship between leaf functional traits, but this trade-off was different among four green space environments.

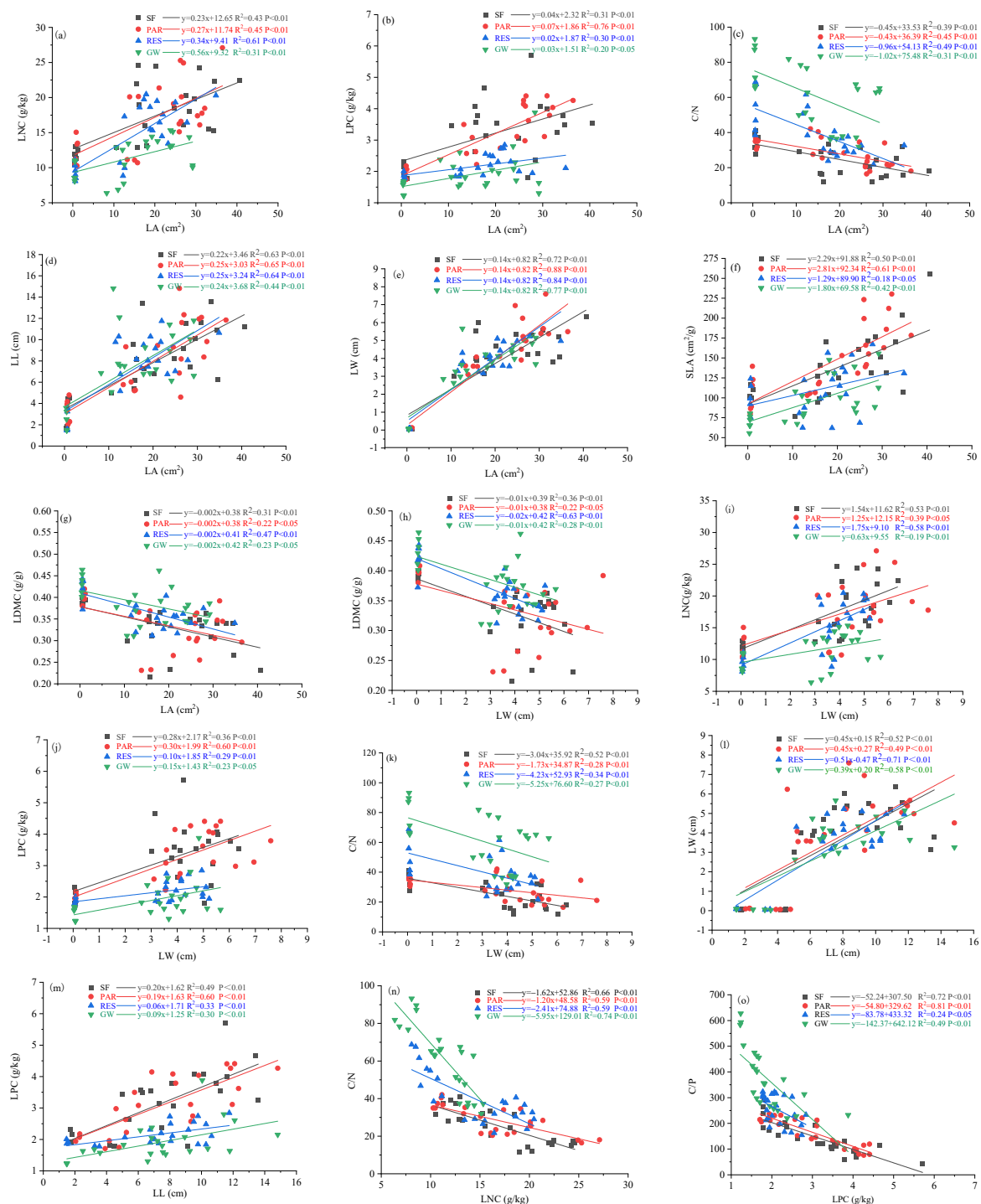


Figure 5. Linear regression between leaf traits with significant correction ($p < 0.05$ or $p < 0.01$) on plants among four green space environments. SF = sport field; PAR = park; RES = residential green space; GW = greenway. LA = leaf area; LL = leaf length; LW = leaf width; SLA = specific leaf area; LDMC = leaf dry matter content; LCC = leaf carbon content; LNC = leaf nitrogen content; LPC = leaf phosphorus content; C/N = leaf carbon/nitrogen ratio; C/P = leaf carbon/phosphorus ratio; N/P = leaf nitrogen/phosphorus ratio. (a) LNC and LA; (b) LPC and LA; (c) C/N and LA; (d) LL and LA; (e) LW and LA; (f) SLA and LA; (g) LDMC and LA; (h) LDMC and LW; (i) LNC and LW; (j) LPC and LW; (k) C/N and LW; (l) LW and LL; (m) LPC and LL; (n) C/N and LNC; (o) C/P and LPC.

4. Discussion

4.1. The Adaptabilities of Landscape Plants to the Different Green Space Environments

Environmental factors promote the optimization of functional strategies by expressing multiple traits, and eventually form a series of trait groups and respond to environmental changes synergistically [48,49]. In our research, the environment had a significant effect on the LW, SLA, LDMC, LCC, LNC, LPC, C/N, C/P, and N/P ($p < 0.001$), and significant effect on the LA ($p < 0.01$). Environment \times plants had significant effects on the LCC, LNC, LPC, C/N, C/P, and N/P ($p < 0.001$), and significant effects on the LDMC ($p < 0.05$) (Table 3). These results indicated that plants in four green spaces had different functional traits due to environmental differences. Plants form survival strategies to adapt to different urban environments through the coordinated changes of various traits.

Leaf traits are the necessary bridge between plants and their environments, which can directly reflect the survival strategies of the plant adaptation to environmental changes [25]. Cities are a comprehensive system of society, economy, and science, which are affected by more interference, and the environment is more complex than the forests [3,33]. A previous study showed that urban landscape plants are sensitive to changes in the urban environment [34,50]. The coefficient of variation (CV) and plasticity index (PI) can reflect the potential adaptability of plants to the different environments [41,51]. Species with higher coefficients of variation and plasticity are more adaptive to the environment [40]. In this study, the mean value of CV and PI of leaf morphological traits was PAR > SF > GW > RES. The mean value of CV and PI of leaf nutrient traits was SF > RES > PAR > GW (Table 4). Large variations and plasticities allow plants in SF and PAR to adapt to various environments, respond better in growing environments, and outperform plants in RES and GW.

Leaf morphological traits and leaf nutrient traits were affected by habitat heterogeneity, changed synergistically in different environments, and produced phenotypic differences. Bussotti [41] believed the CV of leaf morphological traits showed greater variability than nutrients. From the results of this study, in four green spaces, the CV of leaf morphology and leaf nutrient traits of eight plants were 14.636%~35.341% and 2.35%~17.649% (Table 4). The CV of leaf morphological traits was higher than that of leaf nutrient traits. It showed that the variation of plants in four green spaces was abundant, and leaf nutrient traits were more sensitive to the environment than leaf morphological traits. Urban plants may preferentially adjust leaf nutrient traits to adapt to the environmental changes, since leaf nutrient regulation was usually easier and took less time than leaf morphological regulation. Su reported a similar result [40]. A previous study showed the low value of the CV character; the value of PI tends to be low, and vice versa [52]. In our studies, the PIs of leaf morphological traits and leaf nutrient traits in four green spaces were 0.474~0.743 and 0.064~0.284 (Table 4). It showed that leaf morphological PI was also higher than the PI of leaf nutrient traits, consistent with the view of Zulfahmi's [52].

We found that the leaf morphology variation of deciduous shrub (*P. triloba* and *F. suspensa*) in four green spaces was relatively higher among eight plants in four green spaces, but the variation of evergreen shrub (*E. japonicus*) was relatively low. It showed that the leaf morphology of *P. triloba* and *F. suspensa* was more adaptive to the urban green space environment. The reason may be that the growth rate of deciduous shrubs was usually fast, the pruning frequency of shrubs was higher than that of trees, and the management intensity was also more intensive [40]. In addition, shrubs may invest more in root growth and have deeper and finer roots to absorb more water and nutrients. Their height was also lower and required less moisture and fewer nutrients to survive. Therefore, they were able to adapt to changes in the environment successfully [53].

4.2. The Difference in Leaf Functional Traits of Eight Landscape Plants in Four Growing Environments

Environmental conditions, directly and indirectly, influenced plant function through affecting traits [54]. Leaves are organs that directly contact the environment, and leaf functional traits are essential to plant characteristics [55]. Perrin [56] considers that leaf length, leaf width,

and leaf area all increase with more shade, making their structure and function adapt to the changing environment. In the process of responding to competition, their structure will be strongly shaped [57,58]. In this study, the mean values of LL, LW, and LA of eight landscape plants in four green spaces were SF > PAR > RES > GW (Figure 3a–c). The reason may be that plant density and shade of SF and PAR were higher than RES and GW. Therefore, plants in SF could obtain more sunlight by increasing leaf length and leaf width to increase the leaf area and strive for more light resources to produce the greatest photosynthetic benefits. Compared with GW, there were high-rise buildings around the plants in RES; the shading by buildings affected the light resources acquisition of plants in RES.

Some studies have shown that plants facing adversity and living in resource-poor environments had a low SLA and high LDMC. LDMC may be more effective in preventing water losses of the leaf surface [15,59–61]. Plant with lower SLA may be worse light competitors but are considered better competitors for limiting soil conditions [54]. Lanzhou is located in an arid and semiarid area, in which water is the main limiting factor for plant growth [35]. The managers of GW in Lanzhou water them little each year, while SF and PAR have a high maintenance level with well-kept vegetation. In this study, except for *P. asperata* and *P. triloba*, SLA of *C. deodara*, *E. maackii*, *P. cerasifera*, *F. chinensis*, *F. suspensa*, and *E. japonicus* in GW was the least among the four green spaces, and LDMC was the largest in GW. The mean values of SLA and LDMC of eight landscape plants in four green spaces were PAR > SF > RES > GW and GW > RES > PAR > SF (Figure 3d,e). The reason may be that SF and PAR were watered more frequently and had higher soil water content. GW was less watered and soil water content was lower. Under the trade-off between photosynthesis and water, plants in SF and PAR ensured photosynthesis by increasing LA and SLA and reducing LDMC to increase leaf investment, while plants in GW increased tissue buildup in leaves by reducing LA and SLA and increasing LDMC to reduce leaf investment and increase defense structure [62–64]. Additionally, plants with lower SLA would better adapt to the poor soil environment of GW. In a previous study, the disturbance has a certain impact on plant functional traits [65]. Although SF and PAR were managed similarly in the present study, many tourists visited all day in PAR. Human distance may influence plant functional traits.

The leaf C, N, and P are the fundamental chemical elements of the leaf [45]. Their contents are affected by the external environment, which is a comprehensive reflection of plant metabolic capacity and nutrient utilization [66]. Previous studies have shown that plants with high C have a solid defense against adverse external environments [67]. The environment can affect nitrogen and phosphorus content by affecting various biochemical enzymes of leaves, such as sucrose synthase and nitrate reductase. The sucrose synthase and nitrate reductase activities are lower in poor environments [68], while sucrose synthase is one of the critical enzymes for photosynthesis. Nitrate reductase is the rate-limiting enzyme of nitrogen assimilation [69], and it regulates nitrogen metabolism and affects photosynthesis [70]. In this study, the mean contents of LCC of eight landscape plants were GW > RES > PAR > SF, and the mean contents of LNC and LPC were SF > PAR > RES > GW (Figure 4a–c). The reason may be that the water content was lower in GW. In addition, hundreds of vehicles drove near the GW, and the vehicles produced large quantities of harmful gas. The environment of the GW was poorer. Additionally, the average LNC in four green spaces was lower than the global level (20.10 g/kg), the LPC was higher than the global level (1.77 g/kg), and the LCC in SF and PAR was lower than the global level (464.10 g/kg), while LCC in RES and GW was higher than the global level [71,72]. This result was consistent with the conclusion of Wang [73], but opposite to that of Wang [74]. The main reason may be that the biological element content of different plants existed in significant differences. The availability of soil nutrient elements and environmental factors in different regions varied, and the contents of leaf C, N, and P in different growth stages would change [75]. Thus, in this study, the plant growth status (height, diameter at breast height, and canopy diameter) in different green spaces was analogous, ensuring that the changes of leaf morphological traits and leaf nutrient traits and their stoichiometry were caused by the green space environment. Plants

with different life forms have different growth rates, appearances, and longevity, which influence their responses to environmental changes [40]. In our study, most of the LNC and LPC of evergreen trees (*C. deodara*, *P. asperata*, and *E. japonicas*) in four green spaces were lower than deciduous trees (Figure 4b,c). The reason may be that evergreen trees adapted to low nutrient availability and thus have leaves with low nutrient contents [76].

Leaf stoichiometry can help study plant nutrient cycling, nutrient limitations, and plant response to environmental conditions. C/N and C/P of leaves can reflect plants' absorption efficiency of nutrient elements. The higher the ratio, the higher the absorption efficiency of nutrient elements [72]. In this study, the mean values of C/N in SF, PAR, RES, and GW were 25.30, 28.43, 45.23, and 55.06, and higher than the global level (22.50). The mean values of C/P in SF, PAR, RES, and GW were 142.68, 159.43, 253.66, and 373.43 (Figure 4d,e). The mean value of C/P in SF and PAR was lower than the global level (232.00), while the mean value of C/P in RES and GW was higher than the global level [73]. These indicated that, in the present study, the N uptake rate of the landscape plants was higher than the average value of the global plants. The uptake rate of P in SF and PAR was lower than the average value of the global plants, but the uptake rate of P in RES and GW was higher than the average value of the global plants. The average values of C/N and C/P were SF < PAR < RES < GW. The reason may be that, in order to resist the influence of the environmental change, plants may increase the synthesis of related stress-resistant proteins and improve the absorption and utilization efficiency of nutrient elements (such as N and P), resulting in the increase of the ratio of C to nutrient elements [73]. N and P are the nutrients that most frequently limit primary productivity and plant growth [77]. Güsewell [78] proposed that plants were N-limited when at a plant N:P ratio of <10 and P-limited when at a plant N:P ratio of >20. In this study, the N/Ps of plants in SF, PAR, RES, and GW were 5.654, 5.676, 5.838, and 7.746 (Figure 4f). It was shown that landscape plants in the study area were mainly limited by N. The N/Ps of plants were SF < PAR < RES < GW. It may be that the nutrient uptake efficiency of the plant was improved in an adverse environment, so the limitation of N in green space was alleviated.

4.3. The Trade-Off Relationship between Leaf Functional Traits of Eight Landscape Plants in Four Green Space Environments

Some studies showed that plant functional traits significantly vary in the urban area, and there are trade-offs between leaf morphological traits and nutrient-related traits [1]. In four green spaces, the results from this study showed that LA, LL, LW, and SLA were positively correlated with LNC and LPC, except for SLA and LPC in GW, but negatively correlated with C/N and C/P. LDMC was negatively correlated with LNC, LPC, and N/P and positively correlated with C/N (Table 5). Especially, LA and LW had significantly positive correlation with LNC and LPC ($p < 0.01$) (Figure 5a,b,i,j), but significantly negative correlation with C/N ($p < 0.01$) (Figure 5c,k). Previous studies have shown that plants with high SLA and LNC showed relationships with resource-acquisition traits, presenting an acquisitive strategy, while plants with high LDMC and C/N were related to resource-conservation traits, presenting a conservative strategy [1]. This study further confirmed the above point.

Previous studies have shown that the leaf morphological traits are strongly associated with acquiring nutrient resources and water use efficiency to better adapt to different environments [79]. The synergistic growth of leaf length and leaf width determines the leaf area, and then affects the photosynthesis of plants. In reducing the leaf area in dry years, the leaf width tends to decrease preferentially, while in increasing the leaf area in wet years, the leaf length shows the characteristic of preferential growth [80]. The preferential change of leaf width is conducive to the rapid change of leaf area, while the preferential change of leaf length is conducive to the change of leaf circumference and prevents the rapid change of leaf area [81]. The result from this study was that LL had a positively significant correlation with LA and LW ($p < 0.01$), and LW had a positively significant correlation with LA ($p < 0.01$) (Table 5). The lengthening rate was more significant than the widening

rate (Figure 5l). The narrow and long leaves were conducive to the heat dissipation of plant leaves. In addition, the perimeter and structure of the leaf edge were optimized to reduce the leaf boundary resistance and balance the input and output of energy [82]. Nicoleta Ianovici [83] believes leaf area is important for ecophysiological studies. It is vital in research on plant adaption, nutrient utilization, and competition, measures to protect plants, and heat transfer in plants. In this study, LA was significantly correlated with LNC, LPC C/N, LL, LW, SLA, and LDMC among four green spaces ($p < 0.01$) (Table 5). This result showed that, in different environments, LA had synergistic changes with more traits compared with other traits.

C, N, and P play an essential role in the growth and regulation of various physiological mechanisms and reflect the defensive and adaptive strategies of plants to adverse environments [84]. Previous studies have shown that there is a dynamic balance between N and P in plants, and the change is synergetic and simultaneous. When one element changes, the other also changes [45]. The results from this study showed that LNC was significantly positively correlated with LPC in SF and RES ($p < 0.01$), significant positively correlated with LPC in PAR ($p < 0.05$), but not significant positively correlated with LPC in GW ($p > 0.05$) (Table 5). It indicated there was a trade-off between nutrient allocation and fast growth, but the trade-off strategies were various due to different environments.

Ecological stoichiometry usually refers to the elemental composition of an organism, mainly emphasizing the relationship between the main constituent elements (especially C, N, and P) of living organisms. It is influenced by C, N, P, plant lifestyle, and some environmental factors. The response of leaf stoichiometry to the environment reflects plant adaptation strategies to different habitats [72,73]. This study showed that LCC was positively correlated with C/P ($p < 0.01$ or $p < 0.05$) in four green spaces. LNC was negatively correlated with C/N in four green spaces ($p < 0.01$). Except for LPC and C/N in GW, LPC was negatively correlated with C/N and C/P ($p < 0.01$ or $p < 0.05$) (Table 5). In addition, the slopes of the linear regressions of LNC and C/N, and LPN and C/P were different in the four green spaces (Figure 5n,o), indicating that there were differences in the degree of correlation between leaf nutrient traits and stoichiometry. The ecological strategies to adapt to the environment also changed. Due to the difference among the four green space environments, plants' physiological and biochemical processes were changed, affecting the leaf nutrient traits and ecological stoichiometric characteristics directly or indirectly [76]. Different green space environments changed the nutrient availability of landscape plants.

5. Conclusions

Based on landscape plant growth in different green space environments, we analyzed the response of urban landscape plant functional traits to the different green space environments and their adaptation strategies. Differently from other studies, we conducted experiments in an open urban environment. We found that landscape plants' functional traits and ecological adaptation varied among different green space environments in Lanzhou, China. Plants were sensitive to the urban environment and adapted to the environmental changes by adjusting their leaf functional traits and forming different survival strategies. The mean value of LL, LW, LA, and SLA was PAR > SF > RES > GW. LNC and LPC in four green spaces were SF > PAR > RES > GW, and the mean value of LCC, LDMC, C/N, and C/P was GW > RES > PAR > SF. Landscape plants in SF and PAR tended to have an acquisitive strategy with high LL, LW, LA, SLA, LNC, and LPC, while plants in GW tended to have a conservative strategy with high LCC, LDMC, C/N, and C/P. The CV and PI of leaf morphological traits were greater than those of leaf nutrient traits. The mean values of CV and PI of leaf morphological traits were PAR > SF > GW > RES. The mean values of CV and PI of leaf nutrient traits were SF > RES > PAR > GW. The landscape plants in SF and PAR were more adaptive to the urban environment than those in RES and GW. These results will provide a theoretical basis for the allocation, utilization, and management of landscape plants in the environment of deepening urbanization. In addition, this study was

conducted in a northwest city of China; the results generated can be considered preliminary and need to be interpreted prudently, and more research is needed to verify these results in other cities with similar climate and vegetation in China and even in the world.

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