



Supplement of

Soil stoichiometric characteristics and influencing factors in karst forests at microtopography and microhabitat scales

Yi Dang et al.

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Table S1. The correspondence between various factors and the number of sample plots.

Environmental factors	Class	Number of Plots
Slope position	Upslope	6
	Midslope	18
	Downslope	49
	Depression	13
	Flat slope	16
Slope degree	Gentle slope	12
	Tilted slope	14
	Steep slope	27
	Sharp slope	17
	Shady slope	6
Slope aspect	Semi-shady slope	22
	Flat land	16
	Semi-sunny slope	19
	Sunny slope	23
	Stone gully	29
Microhabitat	Stone surface	29
	Soil surface	28
	Evergreen trees	32
Life forms	Deciduous trees	21
	Shrubs	21
	Herbs	12

Table S2. Analytical methods and core instrumentation for determining soil properties.

Detection Indicator	Standard Method	Core Instrumentation
pH	Potentiometric method	pH meter (accuracy ± 0.01)
SOC	Potassium dichromate oxidation - external heating method	Oil bath ($180^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$), Titration apparatus
TN	Semi-micro Kjeldahl method	Kjeldahl nitrogen analyzer, Digestion block/furnace
HN	Alkaline hydrolysis - diffusion method	Constant temperature incubator, Diffusion dish
TP	Alkaline fusion-molybdenum-antimony-ascorbic acid spectrophotometry	Muffle furnace, Spectrophotometer
AP	Hydrochloric-sulfuric acid leaching method	Oscillator/shaker, Spectrophotometer
TK	Alkali fusion - flame photometry	Muffle furnace, Flame photometer
AK	Ammonium acetate extraction - flame photometry	Centrifuge, Flame photometer
TCa & TMg	Atomic absorption spectrophotometry	Atomic Absorption Spectrometer (AAS)
ExCa & ExMg	Ammonium acetate exchange - AAS method	Centrifuge, Atomic Absorption Spectrometer (AAS)

Table S3. Analytical methods and core instrumentation for determining plant properties.

Detection Indicator	Standard Method	Core Instrumentation
C	Potassium dichromate oxidation-external heating method	Oil bath ($180^{\circ}\text{C} \pm 0.5^{\circ}\text{C}$), Titration apparatus
N	Kjeldahl method	Kjeldahl nitrogen apparatus, Digestion furnace
P	Molybdenum-antimony anti-spectrophotometric method	Muffle furnace, Spectrophotometer
K	Flame photometry	Muffle furnace, Flame photometer
Ca & Mg	Atomic absorption spectrophotometry	Atomic absorption spectrometer (AAS)

Table S4. Statistical characteristics of various soil nutrient contents.

Statistical characteristics	Soil	Total	Hydrolyzable	Total	Available	Total	Available	Total	Exchangeable	Total	Exchangeable	pH
	Organic Carbon /(g·kg ⁻¹)	Nitrogen /(g·kg ⁻¹)	Nitrogen /(mg·kg ⁻¹)	Phosphorus /(g·kg ⁻¹)	Phosphorus /(mg·kg ⁻¹)	Potassium /(g·kg ⁻¹)	Potassium /(mg·kg ⁻¹)	Calcium /(g·kg ⁻¹)	Calcium /(cmol·kg ⁻¹)	Magnesium /(g·kg ⁻¹)	Magnesium /(cmol·kg ⁻¹)	
Arithmetic mean	125.08	9.52	495.24	0.87	2.48	13.95	271.65	17.72	10.49	6.51	3.73	7.00
Geometric mean	103.10	11.20	575.80	0.99	3.88	14.45	322.83	22.91	12.43	7.14	4.28	6.98
Median	104.22	10.51	500.08	0.98	2.45	14.48	272.06	19.98	11.40	6.64	3.75	7.07
Standard deviation	78.45	6.21	292.87	0.47	3.71	3.79	191.09	16.44	8.63	3.16	2.44	0.42
Kurtosis	0.46	-0.40	-0.48	-1.09	0.77	1.45	0.02	3.36	8.15	1.42	2.23	2.82
Skewness	1.04	0.70	0.46	0.14	1.32	0.50	0.86	1.50	2.58	1.13	1.51	1.22
Minimum	21.30	2.45	112.70	0.19	0.27	7.21	84.17	2.83	3.87	1.99	1.21	5.40
Maximum	374.73	26.38	1326.12	2.11	15.39	27.55	943.74	94.78	48.69	16.90	13.03	7.92
$P_{(K,S)}$	0.00	0.01	0.00	0.06	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Coefficient of variation	0.62	0.55	0.50	0.47	0.95	0.26	0.59	0.71	0.69	0.44	0.56	0.06

Notes: $CV \leq 0.20$ for weak variability, $0.20 < CV < 0.50$ for moderate variability, and $CV \geq 0.50$ for strong variability. Same as below.

Table S5. Statistical characteristics of various soil stoichiometric ratios.

Statistical characteristics	SOC:TN	SOC:TP	SOC:TK	TN:TP	TN:TK	TP:TK	TCa:TMg	TN:TCa	TN:TMg
Arithmetic mean	10.98	143.00	10.11	12.48	0.91	0.08	3.34	0.60	1.80
Geometric mean	10.83	119.04	7.39	10.99	0.68	0.06	2.72	0.54	1.46
Median	10.80	113.02	6.94	9.94	0.67	0.07	2.78	0.58	1.38
Standard deviation	1.84	102.06	8.11	7.16	0.69	0.05	2.59	0.27	1.34
Kurtosis	1.05	3.98	0.82	3.55	0.42	1.11	15.18	-0.10	3.33
Skewness	0.82	2.03	1.22	1.81	1.16	1.16	3.18	0.53	1.91
Minimum	7.25	32.64	1.11	3.78	0.11	0.01	0.70	0.06	0.30
Maximum	17.05	520.43	35.12	42.69	2.73	0.23	18.76	1.31	6.46
$P_{(K,S)}$	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.20	0.00
Coefficient of variation	0.17	0.71	0.79	0.57	0.75	0.64	0.77	0.44	0.73

30 Notes: $CV \leq 0.20$ for weak variability, $0.20 < CV < 0.50$ for moderate variability, and $CV \geq 0.50$ for strong variability. Same as below.

Table S6. Descriptive statistics of soil nutrients across different slope degrees.

Soil nutrient content	Flat slope	Gentle slope	Tilted slope	Steep slope	Sharp slope
Total Nitrogen/(g·kg ⁻¹)	13.11±6.13a	6.13±8.89c	8.89±6.18bc	6.18±8.91ac	8.91±5.67ab
Hydrolyzable Nitrogen/(mg·kg ⁻¹)	655.39±180.69a	180.69±577.32a	577.32±359.6a	359.6±589.37a	589.37±243.39a
Total Phosphorus/(g·kg ⁻¹)	1.19±0.5a	0.5±1ab	1±0.51ab	0.51±0.98a	0.98±0.44b
Available Phosphorus/(mg·kg ⁻¹)	3.1±4.06bc	4.06±2.04c	2.04±2.17a c	2.17±3.41a	3.41±3.63ab
Total Potassium/(g·kg ⁻¹)	14.55±2.24a	2.24±14.82a	14.82±3.27a	3.27±15.91a	15.91±3.15b
Available Potassium/(mg·kg ⁻¹)	476.29±168.5a	168.5±362.76ab	362.76±178.83bc	178.83±348.98bc	348.98±249.47c
Total Calcium/(g·kg ⁻¹)	28.85±22.56ab	22.56±21.42ab	21.42±18.07ab	18.07±22.38b	22.38±16.14a
Exchangeable Calcium/(cmol·kg ⁻¹)	11.78±3.18ab	3.18±11.15b	11.15±11.73b	11.73±8.89a	8.89±5.12ab
Total Magnesium/(g·kg ⁻¹)	7.84±3.78a	3.78±7.2ab	7.2±3.16a	3.16±7.32b	7.32±2.05a
Exchangeable Magnesium/(cmol·kg ⁻¹)	4.7±1.75a	1.75±3.28ab	3.28±1.12ab	1.12±5.18b	5.18±2.67ab
Soil Organic Carbon/(g·kg ⁻¹)	155.16±88.4a	88.4±99.33b	99.33±74.84b	74.84±95.67ab	95.67±64.58a

Notes: Data in the table are presented as mean ± standard deviation. Different lowercase letters within the same row indicate significant differences among different slope degrees ($P < 0.05$). Same as below.

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Table S7. Descriptive statistics of soil stoichiometric characteristics across different slope degrees.

Soil stoichiometric characteristics	Flat slope	Gentle slope	Tilted slope	Steep slope	Sharp slope
SOC:TN	11.41±2.22ab	10.83±1.08ab	10.63±1.65ab	10.37±1.49b	11.93±2.18a
SOC:TP	149.33±105.79ab	101±45.02b	98.18±38.63b	114.56±54.95b	248.77±144.76a
SOC:TK	11.42±7.95ab	7.98±8.06b	6.54±4.81b	9.56±7.79b	14.2±9.69a
TN:TP	12.39±6.96b	9.12±3.57b	9.27±3.7b	10.97±4.37b	20±9.73a
TN:TK	0.95±0.56ab	0.71±0.69ab	0.62±0.46b	0.98±0.85ab	1.12±0.62a
TP:TK	0.08±0.04a	0.08±0.06a	0.07±0.04a	0.08±0.06a	0.07±0.04a
TCa:TMg	4.24±4.64a	2.76±1.9a	3.01±1.72a	3.31±2.04a	3.24±1.61a
TN:TCa	0.57±0.22ab	0.58±0.31ab	0.53±0.29b	0.71±0.25a	0.55±0.27b
TN:TMg	1.93±1.28ab	1.24±0.69b	1.21±0.55b	2.35±1.78a	1.69±1.08ab

Table S8. Descriptive statistics of soil nutrients across different slope aspects.

Soil nutrient content	Shady slope	Semi-shady slope	Flat land	Semi-sunny slope	Sunny slope
Total Nitrogen/(g·kg ⁻¹)	13.41±7.49ab	12.62±6.08a	13.11±6.13a	10.41±5.84ab	8.60±5.83b
Hydrolyzable Nitrogen/(mg·kg ⁻¹)	632.39±308.56a	591.21±298.03a	655.39±180.69a	530.63±300.81a	528.24±344.72a
Total Phosphorus/(g·kg ⁻¹)	1.17±0.59ab	1.02±0.45ab	1.19±0.50a	0.86±0.45b	0.88±0.42ab
Available Phosphorus/(mg·kg ⁻¹)	3.29±3.96a	4.67±3.60a	3.10±4.06a	2.62±2.18a	4.87±4.32a
Total Potassium/(g·kg ⁻¹)	13.32±4.21a	14.23±2.57a	14.55±2.24a	13.22±3.27a	15.90±5.41a
Available Potassium/(mg·kg ⁻¹)	412.14±256.59ab	340.19±203.48b	476.29±168.50a	223.71±121.80c	258.07±150.41bc
Total Calcium/(g·kg ⁻¹)	26.71±16.95ab	25.08±14.58a	28.85±22.56a	23.48±15.02ab	15.23±12.18b
Exchangeable Calcium/(cmol·kg ⁻¹)	13.07±1.93a	12.28±9.15a	11.78±3.18a	9.63±4.85a	15.15±12.87a
Total Magnesium/(g·kg ⁻¹)	9.05±3.92a	7.49±2.54a	7.84±3.78a	7.86±3.40a	5.22±2.00b
Exchangeable Magnesium/(cmol·kg ⁻¹)	5.08±2.99a	5.34±2.60a	4.70±1.75a	4.21±2.80a	2.83±1.53b
Soil Organic Carbon/(g·kg ⁻¹)	139.36±82.89ab	140.02±82.10a	155.16±88.40a	124.03±80.25ab	86.99±52.25b

Notes: Data in the table are presented as mean ± standard deviation. Different lowercase letters within the same row indicate significant differences among different slope aspects ($P < 0.05$). Same as below.

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Table S9. Descriptive statistics of soil stoichiometric characteristics across different slope aspects.

Soil stoichiometric characteristics	Shady slope	Semi-shady slope	Flat land	Semi-sunny slope	Sunny slope
SOC:TN	10.49±2.6a	10.79±1.7a	11.41±2.22a	11.48±1.95a	10.56±10.31a
SOC:TP	156.99±146.99ab	164.5±118.82a	149.33±105.79ab	162.92±112.89a	97.93±104.14b
SOC:TK	12.4±8.8ab	10.71±7.94a	11.42±7.95a	10.81±8.8ab	7.45±4.21b
TN:TP	13.64±8.6ab	14.67±9.32a	12.39±6.96ab	13.47±7.12ab	9.34±9.9b
TN:TK	1.22±0.93a	0.96±0.6a	0.95±0.56a	0.89±0.63a	0.76±0.35a
TP:TK	0.1±0.07a	0.08±0.05a	0.08±0.04a	0.07±0.04a	0.07±0.05a
TCa:TMg	3.22±2.63a	3.51±1.9a	4.24±4.64a	2.93±1.48a	2.93±2.19a
TN:TCa	0.54±0.16a	0.57±0.23a	0.57±0.22a	0.57±0.33a	0.7±0.69a
TN:TMg	1.72±1.5a	1.87±1.15a	1.93±1.28a	1.43±0.8a	1.97±1.33a

Table S10. Descriptive statistics of soil nutrients across different slope positions.

Soil nutrient content	Upslope	Midslope	Downslope	Depression
Total Nitrogen/(g·kg ⁻¹)	13.59±5.53a	5.98±2.85b	12.36±6.31a	13.00±6.09a
Hydrolyzable Nitrogen/(mg·kg ⁻¹)	530.90±155.11a	276.70±121.69b	667.85±301.67a	663.68±185.38a
Total Phosphorus/(g·kg ⁻¹)	0.60±0.16b	0.46±0.18b	1.15±0.37a	1.32±0.46a
Available Phosphorus/(mg·kg ⁻¹)	4.77±2.39a	4.82±4.36a	3.62±3.39a	3.16±4.46a
Total Potassium/(g·kg ⁻¹)	12.73±2.29a	15.95±4.96a	13.94±3.69a	15.11±2.00a
Available Potassium/(mg·kg ⁻¹)	167.78±42.59c	224.6±152.83bc	322.56±184.03b	531.46±125.23a
Total Calcium/(g·kg ⁻¹)	34.80±16.59a	12.28±12.66b	23.66±13.47a	29.27±23.66a
Exchangeable Calcium/(cmol·kg ⁻¹)	11.92±3.57ab	8.39±4.78b	14.01±10.57a	12.27±2.69a
Total Magnesium/(g·kg ⁻¹)	12.52±4.38a	5.42±2.89b	6.98±2.41ab	7.61±2.91ab
Exchangeable Magnesium/(cmol·kg ⁻¹)	6.09±4.7a	3.05±2.38b	4.31±2.08a	5.04±1.73a
Soil Organic Carbon/(g·kg ⁻¹)	189.42±91.02a	69.65±33.87b	130.92±76.18a	150.09±88.34a

Notes: Data in the table are presented as mean ± standard deviation. Different lowercase letters within the same row indicate significant differences among different slope positions ($P < 0.05$). Same as below.

Table S11. Descriptive statistics of soil stoichiometric characteristics across different slope positions.

Soil stoichiometric characteristics	Upslope	Midslope	Downslope	Depression
SOC:TN	13.5±3.04ab	11.66±0.95a	10.39±1.53b	11.08±2.02ab
SOC:TP	326.58±167.72a	168.07±102.66b	117.33±73.36c	120.32±67.53bc
SOC:TK	15.84±8.53a	4.94±3.28b	11.16±8.6a	10.68±7.98a
TN:TP	22.91±8.04a	14.49±8.99c	10.99±5.54b	10.51±5.05bc
TN:TK	1.13±0.57ab	0.43±0.29b	1.05±0.77a	0.91±0.53a
TP:TK	0.05±0.02b	0.03±0.02b	0.09±0.05a	0.09±0.04a
TCa:TMg	2.83±1.18ab	1.97±0.98b	3.59±1.91a	4.55±5.11a
TN:TCa	0.44±0.18b	0.71±0.32a	0.6±0.27ab	0.54±0.16ab
TN:TMg	1.24±0.83ab	1.2±0.37a	2.06±1.52b	1.93±1.38ab

Table S12. Descriptive statistics of soil nutrients across different microhabitats.

Soil nutrient content	Soil surface	Stone surface	Stone gully
Total Nitrogen/(g·kg ⁻¹)	7.34±3.71b	14.55±6.58a	14.55±6.58a
Hydrolyzable Nitrogen/(mg·kg ⁻¹)	468.94±250.35b	681.92±282.46a	681.92±282.46ab
Total Phosphorus/(g·kg ⁻¹)	0.85±0.44b	1.15±0.52a	1.15±0.52ab
Available Phosphorus/(mg·kg ⁻¹)	2.63±3.19b	4.59±3.84a	4.59±3.84a
Total Potassium/(g·kg ⁻¹)	15.61±3.65a	13.15±3.2b	13.15±3.2ab
Available Potassium/(mg·kg ⁻¹)	278.87±173.36b	393.87±221.63a	393.87±221.63ab
Total Calcium/(g·kg ⁻¹)	13.4±8.51c	32.21±18.68a	32.21±18.68b
Exchangeable Calcium/(cmol·kg ⁻¹)	9.52±7.07b	14.93±9.49a	14.93±9.49a
Total Magnesium/(g·kg ⁻¹)	6±2.14b	8.86±4.07a	8.86±4.07b
Exchangeable Magnesium/(cmol·kg ⁻¹)	3.78±1.99b	4.95±2.61a	4.95±2.61ab
Soil Organic Carbon/(g·kg ⁻¹)	79.79±41.53b	171.19±94.45a	171.19±94.45a

Notes: Data in the table are presented as mean ± standard deviation. Different lowercase letters within the same row indicate significant differences among different microhabitats ($P < 0.05$). Same as below.

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Table S13. Descriptive statistics of soil stoichiometric characteristics across different microhabitats.

Soil stoichiometric characteristics	Soil surface	Stone surface	Stone gully
SOC:TN	10.89±1.45a	11.33±2.12a	10.7±1.87a
SOC:TP	103.9±45.84b	178.21±129.58a	145.54±99.91ab
SOC:TK	5.87±4.77c	14.36±9.35a	9.95±7.33b
TN:TP	9.43±3.83b	14.84±9.05a	13.07±6.66a
TN:TK	0.54±0.45b	1.22±0.69a	0.95±0.73a
TP:TK	0.06±0.04b	0.09±0.05a	0.07±0.05ab
TCa:TMg	2.22±1.2b	4.31±3.63a	3.45±1.89a
TN:TCa	0.66±0.27a	0.52±0.22b	0.63±0.29ab
TN:TMg	1.32±0.84a	2.1±1.6a	1.97±1.35a

Table S14. Descriptive statistics of soil nutrients across different plant life forms.

Soil nutrient content	Evergreen trees	Deciduous trees	Shrubs	Herbs
Total Nitrogen/(g·kg ⁻¹)	10.31±6.22b	9.34±5.84b	12.27±5.76ab	14.99±6.34a
Hydrolyzable Nitrogen/(mg·kg ⁻¹)	455.25±254.84c	512.46±251.33bc	643.79±264.59ab	889.1±267.92a
Total Phosphorus/(g·kg ⁻¹)	0.91±0.51bc	0.78±0.37c	1.15±0.41ab	1.31±0.37a
Available Phosphorus/(mg·kg ⁻¹)	4.05±3.8a	4.97±4.62a	2.4±1.79a	4.14±3.83a
Total Potassium/(g·kg ⁻¹)	15.38±3.57a	16.16±3.63a	12.77±2.98b	11.93±3.84b
Available Potassium/(mg·kg ⁻¹)	289.82±158.41a	345.42±218.77a	319.77±189.84a	376.73±227.08a
Total Calcium/(g·kg ⁻¹)	19.2±14.13b	20.06±16.34ab	28.38±19.01ab	28.2±15.49a
Exchangeable Calcium/(cmol·kg ⁻¹)	11.58±5.33a	11.57±4.05a	10.42±4.54a	19.71±18.94a
Total Magnesium/(g·kg ⁻¹)	7.09±3.79a	7.42±3.06a	7.61±2.37a	5.94±2.71a
Exchangeable Magnesium/(cmol·kg ⁻¹)	3.04±1.24b	5.43±3.28a	4.05±1.44a	5.95±2.85a
Soil Organic Carbon/(g·kg ⁻¹)	107.3±64.47b	116.62±92.52b	138.34±77.38ab	164.09±79.62a

Notes: Data in the table are presented as mean ± standard deviation. Different lowercase letters within the same row indicate significant differences among different plant life forms ($P < 0.05$). Same as below.

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Table S15. Descriptive statistics of soil stoichiometric characteristics across different plant life forms.

Soil stoichiometric characteristics	Evergreen trees	Deciduous trees	Shrubs	Herbs
SOC:TN	10.68±1.82a	11.62±2.17a	10.85±1.45a	10.87±1.81a
SOC:TP	138.15±91.16a	176.74±152.97a	129.21±74.44a	121.02±36.2a
SOC:TK	7.8±6.05b	8.54±8.83b	11.94±7.87a	15.81±9.45a
TN:TP	12.57±6.61a	14.12±10.44a	11.51±5.81a	11.09±2.22a
TN:TK	0.76±0.62bc	0.66±0.57c	1.05±0.59ab	1.48±0.88a
TP:TK	0.06±0.04b	0.05±0.03b	0.09±0.04a	0.13±0.07a
TCa:TMg	2.73±1.81b	2.62±1.85b	4.01±3.58a	5.09±2.58a
TN:TCa	0.67±0.28a	0.61±0.25ab	0.49±0.19b	0.61±0.33ab
TN:TMg	1.67±1.18ab	1.34±0.9b	1.71±0.93ab	3.12±2.11a

Table S16. Spearman's rank correlation coefficients between soil stoichiometric characteristics and environmental factors

Stoichiometry	Correlation coefficient with each factor				
	Microhabitat	Slope position	Slope aspect	Slope degree	Life forms
TN	0.470**	0.038	-0.328**	0.241*	0.266*
HN	0.296**	-0.221*	-0.169	0.386**	0.451**
TP	0.253*	-0.235*	-0.188	0.604**	0.330**
AP	0.259*	0.301**	0.031	-0.215*	-0.027
TK	-0.264*	-0.202	0.092	0.028	-0.387**
AK	0.245*	-0.451**	-0.283**	0.522**	0.113
TCa	0.508**	-0.02	-0.306**	0.19	0.317**
ExCa	0.350**	0.095	-0.022	0.184	0.053
TMg	0.339**	-0.04	-0.344**	-0.026	-0.02
ExMg	0.216*	-0.019	-0.440**	0.18	0.366**
SOC	0.456**	0.039	-0.306**	0.142	0.258*
SOC:TN	0.082	0.012	0.02	-0.332**	0.04
SOC:TP	0.283**	0.266*	-0.18	-0.416**	-0.03
SOC:TK	0.450**	0.102	-0.254*	0.096	0.339**
TN:TP	0.310**	0.312**	-0.223*	-0.384**	-0.051
TN:TK	0.436**	0.117	-0.21	0.145	0.347**
TP:TK	0.278**	-0.072	-0.125	0.423**	0.452**
TCa:TMg	0.373**	-0.006	-0.121	0.253*	0.390**
TN:TCa	-0.227*	0.067	0.152	-0.031	-0.184
TN:TMg	0.233*	0.078	-0.044	0.233*	0.270*

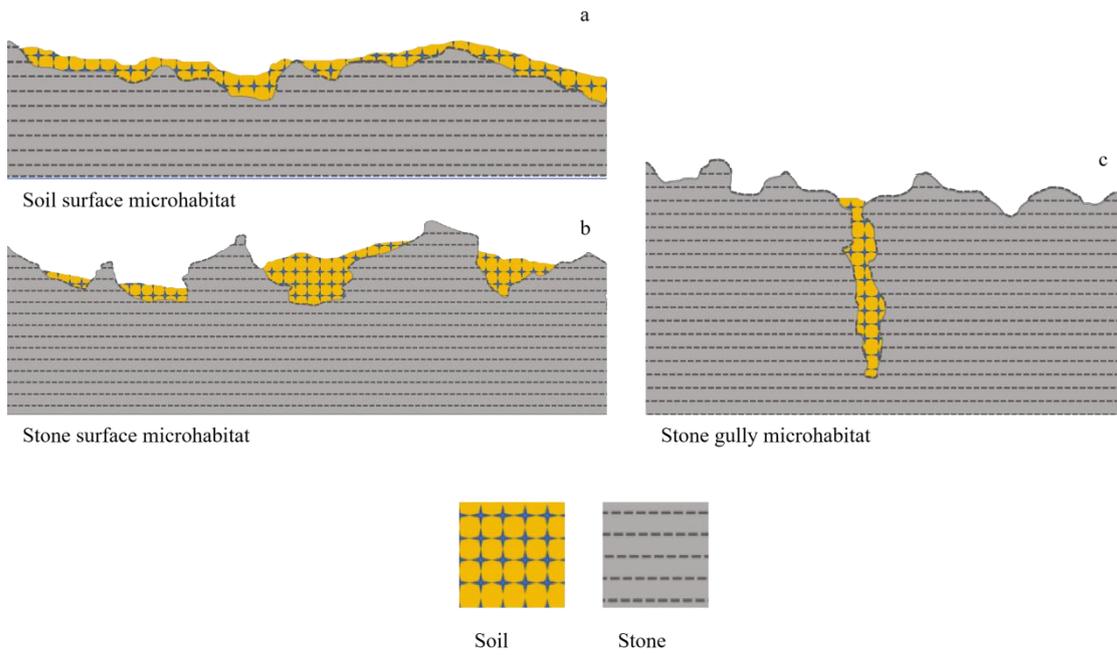


Figure S1. Schematic diagram of stone and soil distribution under different microhabitat types.

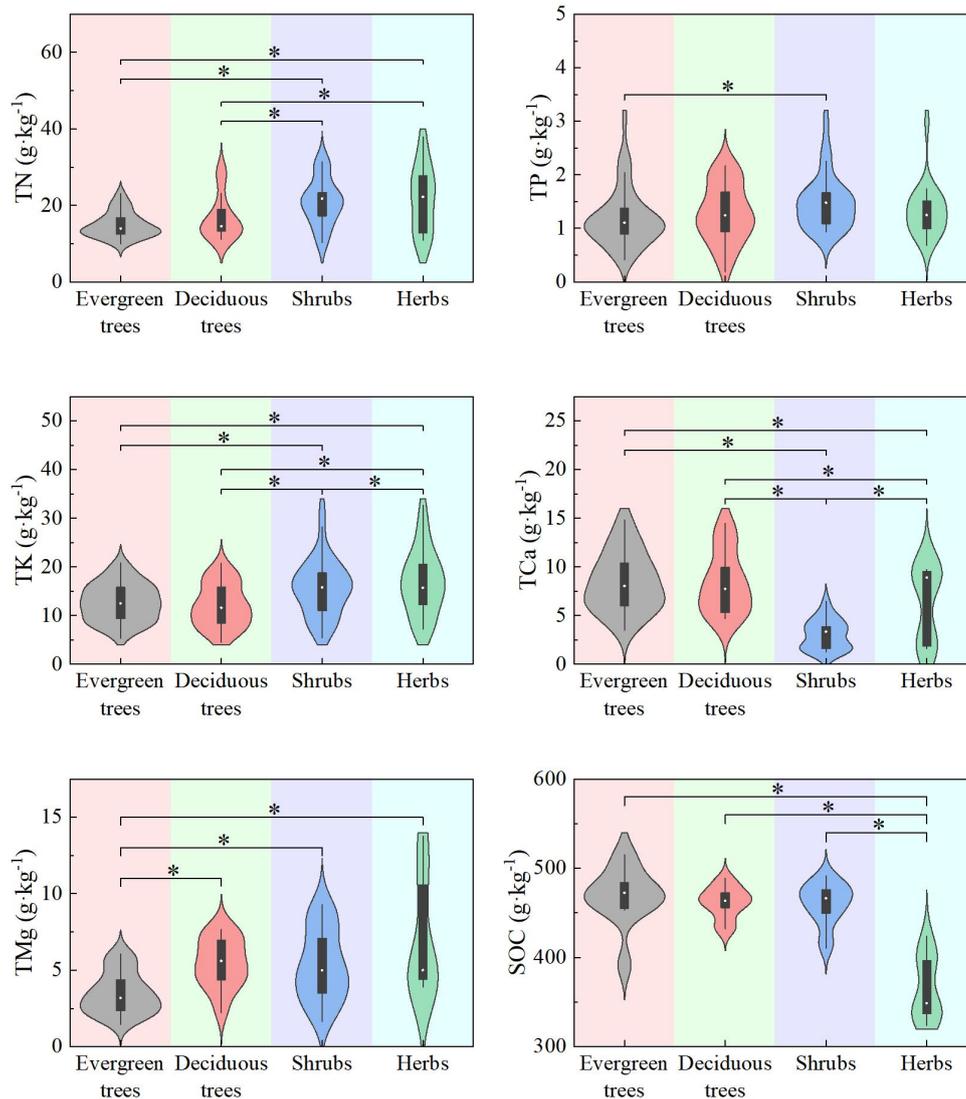


Figure S3. Distribution differences in plant nutrient contents among life forms, presented as violin plots overlaid with box plots. The Y-axis indicates nutrient content values, while the X-axis represents plant life forms. Significant differences ($P < 0.05$) are marked by an asterisk (*), with connecting black horizontal lines identifying the differing groups. Sample sizes (n) are as follows: evergreen trees (n=32), deciduous trees (n=21), shrubs (n=21), herbs (n=12).