Trait-Mediated Responses of Symbiotic Microorganisms to Environmental Stressors: Implications for Human Skin and Wound Healing

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The following Supporting Information is available for this article:

Fig. S1 Lichen species used and experimental work.

Fig. S2 View of the experimental site (a) and details of simulated climate change treatments: warming, consisting of OTC (b), and the combination of warming and reduced precipitation, consisting of OTC + rainfall shelter (c).

Fig. S3 Differences in air temperature between climate change treatments (warming and warming + rainfall reduction) and control plots.

Fig. S4 Changes in each soil property for the studied species under simulated climate change.

Fig. S5. Relationships between lichen C and N composition variables ($\delta^{13}C$, N, C:N) significantly correlated ($P < 0.05$) to changes in the combination of soil properties (NMDS ordination; see Fig. 4) and C-related individual soil properties for each species.

Fig. S6. Relationships between lichen C and N composition variables ($\delta^{13}C$, N, C:N) significantly correlated ($P < 0.05$) to changes in the combination of soil properties (NMDS ordination; see Fig. 4) and N-related individual soil properties for each species.

Fig. S7. Relationships between lichen C and N composition variables ($\delta^{13}C$, N, C:N) significantly correlated ($P < 0.05$) to changes in the combination of soil properties (NMDS ordination; see Fig. 4) and β-glucosidase activity (β-glu.,), acid phosphatase activity (A. pho.), and pH for each species.

Table S1 Results of the one-way PERMANOVA analysis for lichen C and N composition variables based on species data.

Table S2 Results of the two-way (species and climate change treatments) PERMANOVA analysis of RII values for each soil variable.

Table S3 Correlation coefficients between lichen C and N composition variables and changes in the combination of soil properties (NMDS ordination; see Fig. 4).

Table S4 Results of the two-way (species and climate change treatments) PERMANOVA for soil data.

Table S5 Results of the two-way (species and climate change treatments) PERMANOVA analysis for each soil variable.

Fig. S1 Biocrust-forming lichen species used and experimental work. (a) A photograph of the area where the lichen fragments were collected, characterized by *Stipa tenacissima* tussocks and biocrusts dominating plant interspaces. Lichen species (i) *Buellia zoharyi*, (j) *Diploschistes diacapsis*, (k) *Psora decipiens* and (l) *Squamarina lentigera*. These species show important variations in key functional traits such as the chemical composition, type and colour of thallus: *B. zoharyi* (i); crustose, white coloured and semi-continuous thallus containing atranorin, norstictic and stictic acids, *D. diacapsis* (j); crustose, continuous and white coloured thallus containing diploschistesic and lecanoric acids (major concentrations), *P. decipiens* (k);

squamulose, discontinuous, orange coloured thallus with fruiting bodies containing anthraquinones, and *S. lentigera* (l); squamulose-crustose, continuous thallus containing usnic acid (Trinkaus & Mayrhofer, 2000; Molnár & Farkas, 2010; Nimis, 2016). View of the biocrust material collected in the field (f) and preparation of lichen material into pieces of 1.21 cm2 (f, g, h). View of biocrust microcosms (diameter=20 cm) for the different studied species: *B. zoharyi* (j), *D. diacapsis* (j), *P. decipiens* (k) and *S. lentigera* (l).

Fig. S2 View of the experimental site (a) and details of simulated climate change treatments: warming, consisting of OTC (b), and the combination of warming and reduced precipitation, consisting of OTC + rainfall shelter (c).The OTCs were built with six methacrylate plates that followed a hexagonal design with sloping sides of 65-52-42 cm (b). The methacrylate material used to build them transmits ~92% of the visible spectrum, has a 4% of the emission of the infrared wavelength and pass on 85% of incoming energy (data provided by the manufacturer, Decorplax Metacrilatos S.L., Madrid, Spain). Each rainfall shelter has an area of 1.68 m2 (1.4 m × 1.2 m), and a mean height of 1 m, and a roof composed of six methacrylate grooves (c), which covers approximately 35% of the surface.

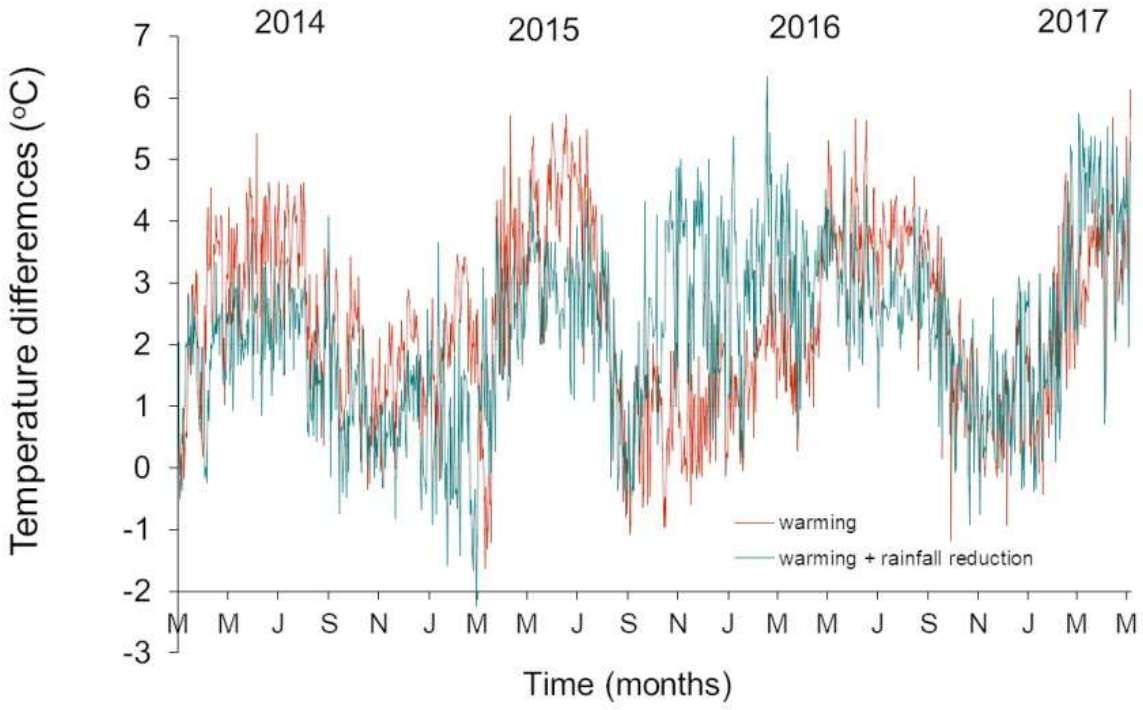

Fig. S3 Differences in air temperature between climate change treatments (warming and warming + rainfall reduction) and control plots.

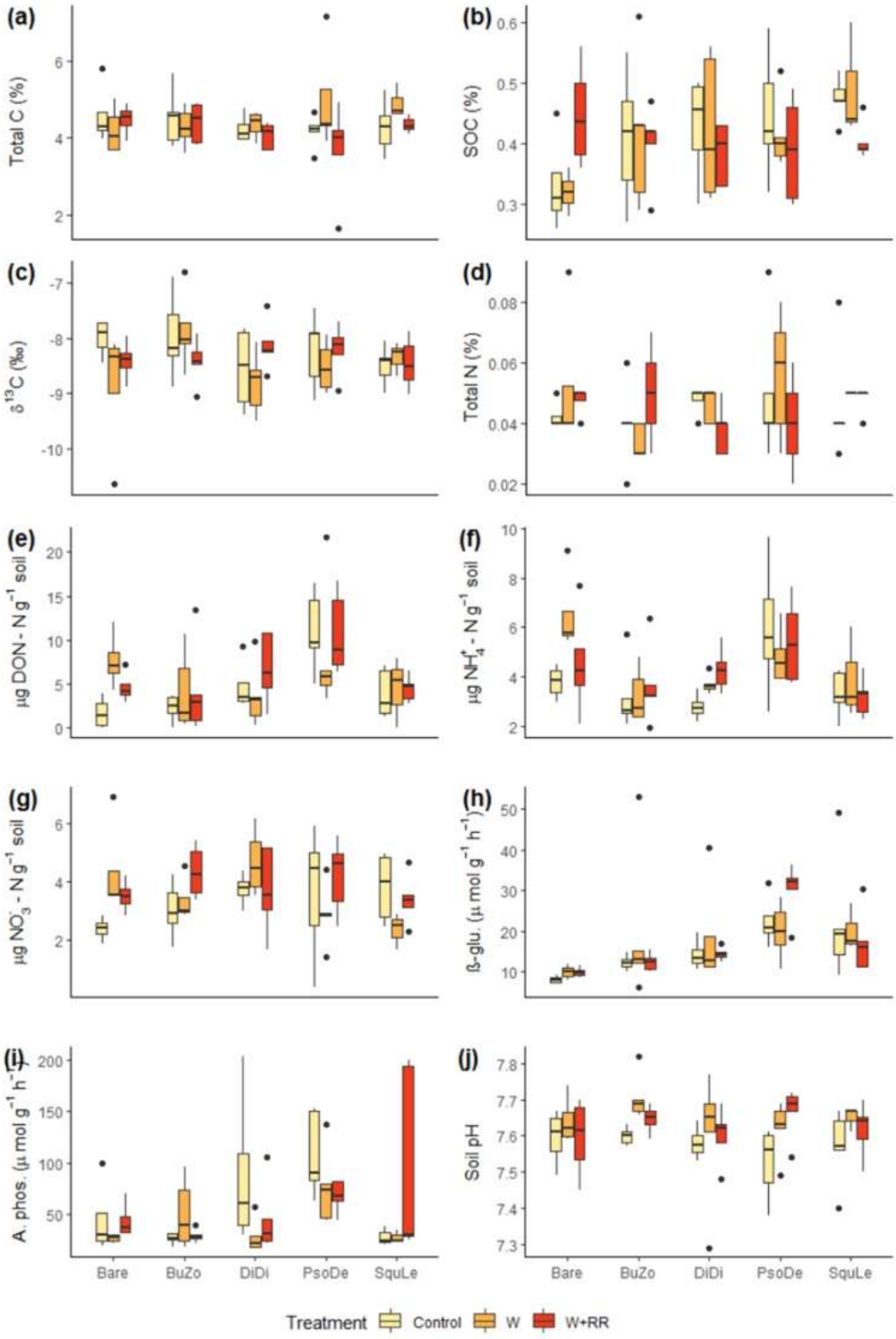

Fig. S4 Changes in each soil property for the studied species under simulated climate change. Panels show soil (a) total C content; (b) organic matter content; (c) C isotope ratio ($\delta^{13}C$); (d) total N concentration; (e) dissolved organic N (DON) concentration; (f) ammonium (NH_4^+)

concentration; (g) nitrate (NO_3^-) concentration; (h) β-glucosidase activity; (i) acid phosphatase activity; and (j) pH. Boxes show the median, 25th and 75th percentiles; vertical lines show the minimum and maximum values that fall within 1.5 times the height of the box. Bare, bare soil; BuZo, *Buellia zoharyi*; DiDi, *Diploschistes diacapsis*; PsoDe, *Psora decipiens*; SquLe, *Squamarina lentigera*; W, warming and W+RR, warming and rainfall reduction.

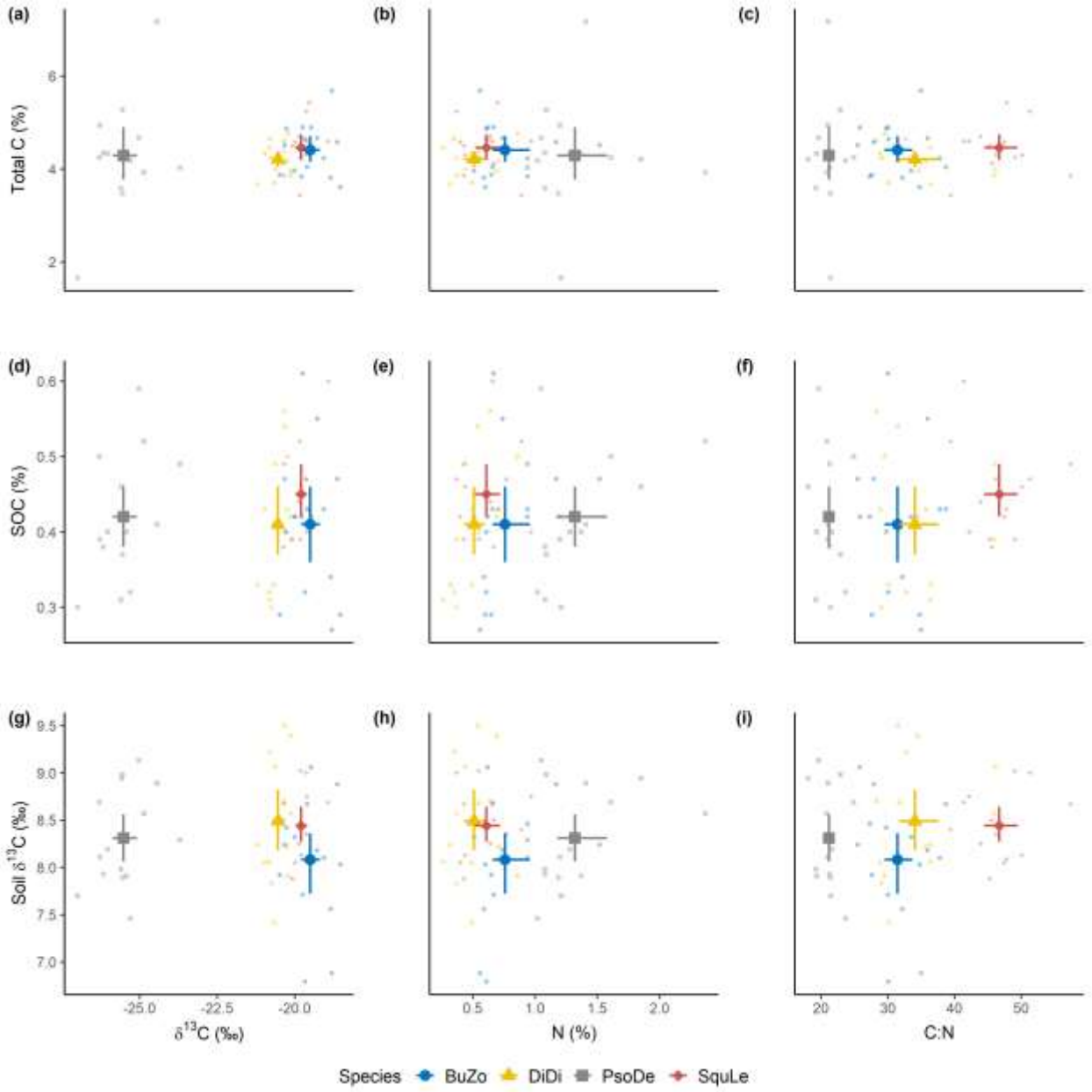

Fig. S5 Relationships between lichen C and N composition variables significantly correlated ($P < 0.05$) to changes in the combination of soil properties (NMDS ordination; see Fig. 4) and C-related individual soil properties for each species. Panels show lichen C isotope ratio ($\delta^{13}C$) (a,d,g), total N content (b,e,h) and C:N ratio (c,f,i) versus soil total C content (a-c), organic C (d-f) and C isotope ratio ($\delta^{13}C$) (g-i). Data are mean ± 95% bootstrap CIs.

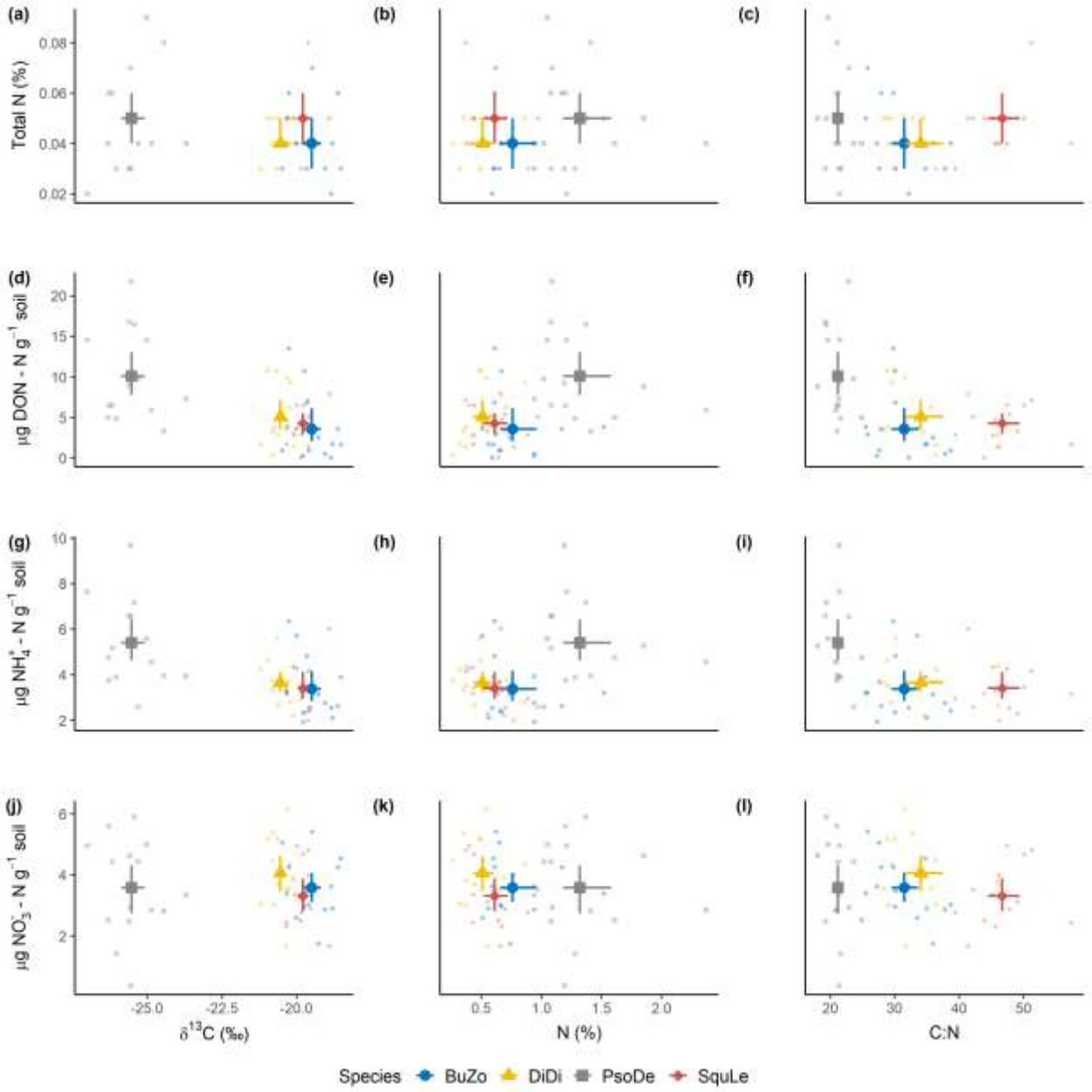

Fig. S6 Relationships between lichen C and N composition variables significantly correlated ($P < 0.05$) to changes in the combination of soil properties (NMDS ordination; see Fig. 4) and N-related individual soil properties for each species. Panels show lichen C isotope ratio ($\delta^{13}C$) (a,d,g,j), total N content (b,e,h,k) and C:N ratio (c,f,i,l) versus soil total N content (a-c), dissolved organic N (DON) concentration (d-f), ammonium (NH_4^+) concentration (g-i) and nitrate (NO_3^-) concentration (j-l). Data are mean ± 95% bootstrap CIs.

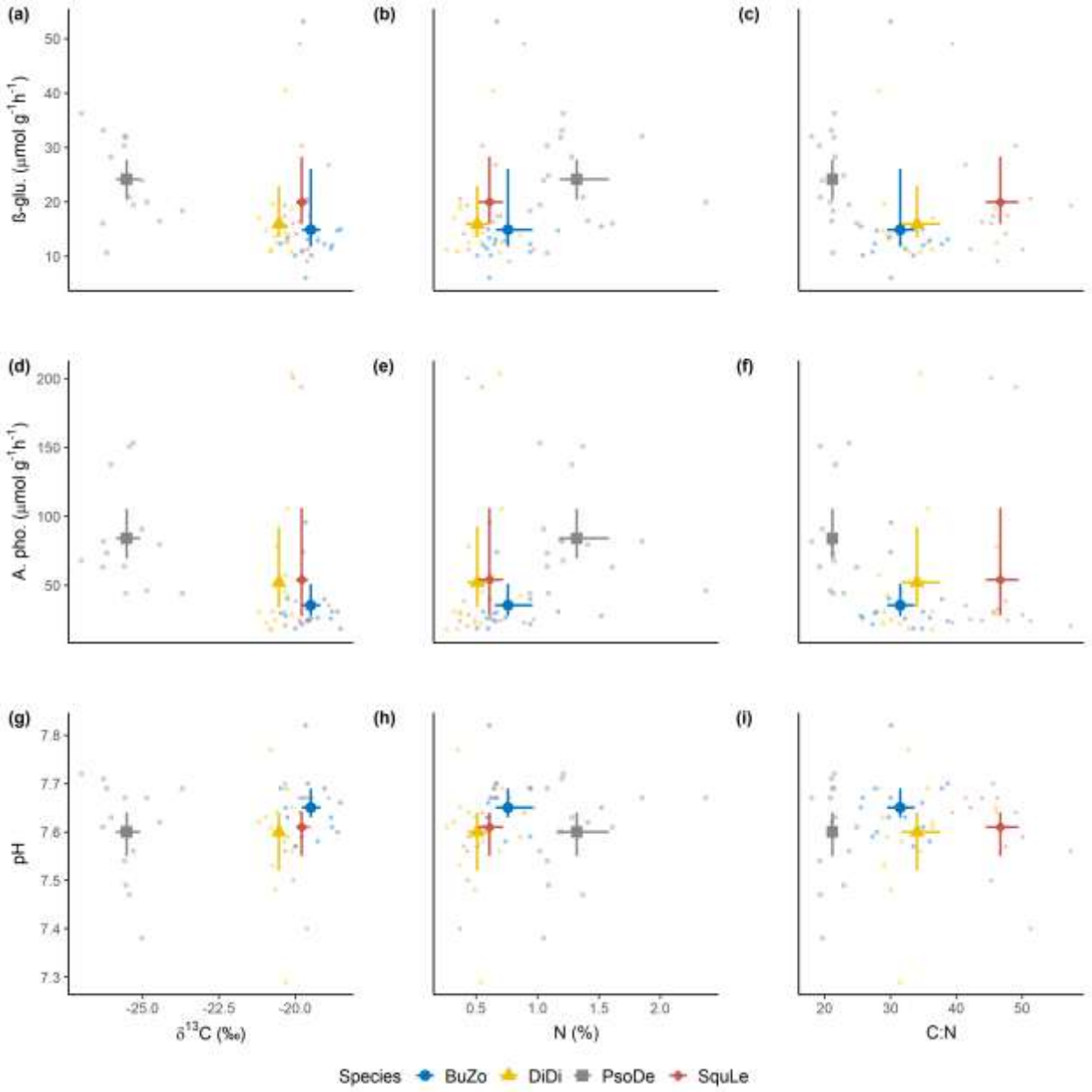

Fig. S7 Relationships between lichen C and N composition variables significantly correlated ($P < 0.05$) to changes in the combination of soil properties (NMDS ordination; see Fig. 4) and soil enzymatic activities and pH for each species. Panels show lichen C isotope ratio ($\delta^{13}C$) (a,d,g), total N content (b,e,h) and C:N ratio (c,f,i) versus soil β-glucosidase (a-c) and acid phosphatase activity (d-f) and pH (g-i). Data are mean ± 95% bootstrap CIs.

Table S1 Results of the one-way PERMANOVA analysis for lichen C and N composition variables based on species data. *B. zoharyi*, *Buellia zoharyi*; *D. diacapsis*, *Diploschistes diacapsis*; *P. decipiens*, *Psora decipiens*; *S. lentigera*, *Squamarina lentigera*.

Species	Lichen variables	Source	Df	Mean square	Pseudo-F	*P*
B. zoharyi	C	Treatment	2	1.64	0.03	0.968
		Residuals	12	58.89		
		Total	14			
	$\delta^{13}C$	Treatment	2	1.27	5.04	0.035
		Residuals	12	0.25		
		Total	14			
	N	Treatment	2	0.04	0.55	0.636
		Residuals	12	0.08		
		Total	14			
	$\delta^{15}N$	Treatment	2	0.39	0.65	0.593
		Residuals	12	0.60		
		Total	14			
	C:N	Treatment	2	70.89	7.17	0.015
		Residuals	12	9.89		
		Total	14			
D. diacapsis	C	Treatment	2	32.54	1.20	0.330
		Residuals	11	27.01		
		Total	13			
	$\delta^{13}C$	Treatment	2	0.09	0.72	0.488
		Residuals	11	0.12		
		Total	13			

	N	Treatment	2	0.03	0.94	0.426
		Residuals	11	0.03		
		Total	13			
	$\delta^{15}N$	Treatment	2	1.36	0.89	0.454
		Residuals	11	1.54		
		Total	13			
	C:N	Treatment	2	8.83	0.23	0.823
		Residuals	11	37.99		
		Total	13			
P. decipiens	C	Treatment	2	43.71	0.66	0.536
		Residuals	12	66.18		
		Total	14			
	$\delta^{13}C$	Treatment	2	0.06	0.08	0.915
		Residuals	12	0.76		
		Total	14			
	N	Treatment	2	0.06	0.40	0.747
		Residuals	12	0.16		
		Total	14			
	$\delta^{15}N$	Treatment	2	0.49	0.32	0.727
		Residuals	12	1.52		
		Total	14			
	C:N	Treatment	2	3.64	1.24	0.320
		Residuals	12	2.95		
		Total	14			
S. lentigera	C	Treatment	2	8.34	0.14	0.873

	Residuals	10	58.01		
	Total	12			
$\delta^{13}C$	Treatment	2	0.25	2.17	0.160
	Residuals	10	0.12		
	Total	12			
N	Treatment	2	0.01	0.20	0.828
	Residuals	10	0.04		
	Total	12			
$\delta^{15}N$	Treatment	2	7.33	30.57	0.002
	Residuals	10	0.24		
	Total	12			
C:N	Treatment	2	15.19	0.64	0.550
	Residuals	10	23.69		
	Total	12			

Table S2 Results of the two-way PERMANOVA (species and climate change treatments) analysis of RII values for each soil variable. Total C, total carbon; Total N, total nitrogen; SOC, soil organic carbon; total N, total nitrogen; DON, dissolved organic nitrogen; β-glucosidase, β-glucosidase activity; Acid phosphatase, acid phosphatase activity.

	Source	Df	Mean square	Pseudo-F	*P*
Total C	Species	3	0.00	0.39	0.770
	Treatment	2	0.05	6.31	0.002
	Species x Treatment	6	0.01	1.12	0.372
	Residuals	45	0.01		
	Total	56			
SOC	Species	3	0.01	0.62	0.625
	Treatment	2	0.26	25.10	0.001
	Species x Treatment	6	0.00	0.19	0.985
	Residuals	45	0.01		
	Total	56			
$\delta^{13}C$	Species	3	0.00	1.79	0.167
	Treatment	2	0.01	8.14	0.001
	Species x Treatment	6	0.00	1.24	0.329
	Residuals	45	0.00		
	Total	56			
Total N	Species	3	0.03	1.41	0.262
	Treatment	2	0.11	5.67	0.008
	Species x Treatment	6	0.02	1.16	0.341
	Residuals	45	0.02		
	Total	56			
DON	Species	3	0.84	5.93	0.002
	Treatment	2	2.09	14.83	0.001
	Species x Treatment	6	0.05	0.37	0.887

	Residuals	45	0.14		
	Total	56			
NH_4^+	Species	3	0.16	6.60	0.001
	Treatment	2	0.28	11.91	0.001
	Species x Treatment	6	0.02	0.75	0.607
	Residuals	45	0.02		
	Total	56			
NO_3^-	Species	3	0.02	0.57	0.619
	Treatment	2	0.41	10.26	0.002
	Species x Treatment	6	0.05	1.16	0.359
	Residuals	45	0.04		
	Total	56			
β-glucosidase	Species	3	0.18	6.02	0.004
	Treatment	2	0.03	0.92	0.407
	Species x Treatment	6	0.02	0.69	0.659
	Residuals	45	0.03		
	Total	56			
Acid phosphatase	Species	3	0.55	9.07	0.001
	Treatment	2	0.15	2.40	0.111
	Species x Treatment	6	0.16	2.66	0.037
	Residuals	45	0.06		
	Total	56			
pH	Species	3	0.00	1.16	0.340
	Treatment	2	0.00	2.80	0.058
	Species x Treatment	6	0.00	0.69	0.696
	Residuals	45	0.00		
	Total	56			

Table S3 Correlation coefficients between lichen C and N composition variables and changes in the combination of soil properties (NMDS ordination; see Fig. 4).

	Lichen variable	R^2	*P*
Axes 1 and 2	C	0.01	0.705
	$\delta^{13}C$	0.42	0.001
	N	0.13	0.029
	$\delta^{15}N$	0.05	0.235
	C:N	0.22	0.001
Axes 1 and 3	C	0.06	0.175
	$\delta^{13}C$	0.42	0.001
	N	0.14	0.020
	$\delta^{15}N$	0.06	0.178
	C:N	0.22	0.002
Axes 2 and 3	C	0.07	0.112
	$\delta^{13}C$	0.00	0.921
	N	0.01	0.818
	$\delta^{15}N$	0.01	0.773
	C:N	0.02	0.504

Table S4 Results of the two-way (species and climate change treatments) PERMANOVA for soil data.

Source	Df	Mean square	Pseudo-F	*P*
Species	3	0.74	3.29	0.001
Treatment	2	0.16	0.70	0.757
Species x Treatment	6	0.28	1.22	0.175
Residuals	45	0.23		
Total	56			

Table S5 Results of the two-way (species and climate change treatments) PERMANOVA analysis for each soil variable. Total C, total carbon; SOC, soil organic carbon; total N, total nitrogen; DON, dissolved organic nitrogen; β-glucosidase, β-glucosidase activity; Acid phosphatase, acid phosphatase activity.

	Source	Df	Mean square	Pseudo-F	*P*
Total C	Species	4	0.14	0.31	0.884
	Treatment	2	0.74	1.58	0.233
	Species x Treatment	8	0.56	1.20	0.308
	Residuals	54	0.47		
	Total	68			
SOC	Species	4	0.01	1.58	0.197
	Treatment	2	0.00	0.27	0.780
	Species x Treatment	8	0.01	1.20	0.294
	Residuals	54	0.01		
	Total	68			
$\delta^{13}C$	Species	4	0.39	1.09	0.368
	Treatment	2	0.32	0.91	0.425
	Species x Treatment	8	0.41	1.16	0.323
	Residuals	54	0.35		
	Total	68			
Total N	Species	4	0.00	0.71	0.606
	Treatment	2	0.00	0.26	0.779
	Species x Treatment	8	0.00	1.04	0.415
	Residuals	54	0.00		
	Total	68			
DON	Species	4	100.12	6.24	0.002
	Treatment	2	11.77	0.73	0.482
	Species x Treatment	8	13.26	0.83	0.603

	Residuals	54	16.05		
	Total	68			
NH_4^+	Species	4	12.79	6.16	0.001
	Treatment	2	1.53	0.74	0.488
	Species x Treatment	8	2.87	1.38	0.198
	Residuals	54	2.08		
	Total	68			
NO_3^-	Species	4	1.13	0.83	0.519
	Treatment	2	1.40	1.04	0.389
	Species x Treatment	8	2.62	1.94	0.088
	Residuals	54	1.35		
	Total	68			
β-glucosidase	Species	4	418.34	5.70	0.001
	Treatment	2	20.50	0.28	0.760
	Species x Treatment	8	70.26	0.96	0.506
	Residuals	54	73.38		
	Total	68			
Acid phosphatase	Species	4	5421.10	3.54	0.014
	Treatment	2	1406.60	0.92	0.428
	Species x Treatment	8	3334.70	2.18	0.045
	Residuals	54	1531.20		
	Total	68			
pH	Species	4	0.01	0.91	0.469
	Treatment	2	0.03	4.24	0.015
	Species x Treatment	8	0.00	0.62	0.732
	Residuals	54	0.01		
	Total	68			

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