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Tree growth and water-use efficiency at the Himalayan fir treeline and lower altitudes: roles of climate warming and CO_2 fertilization

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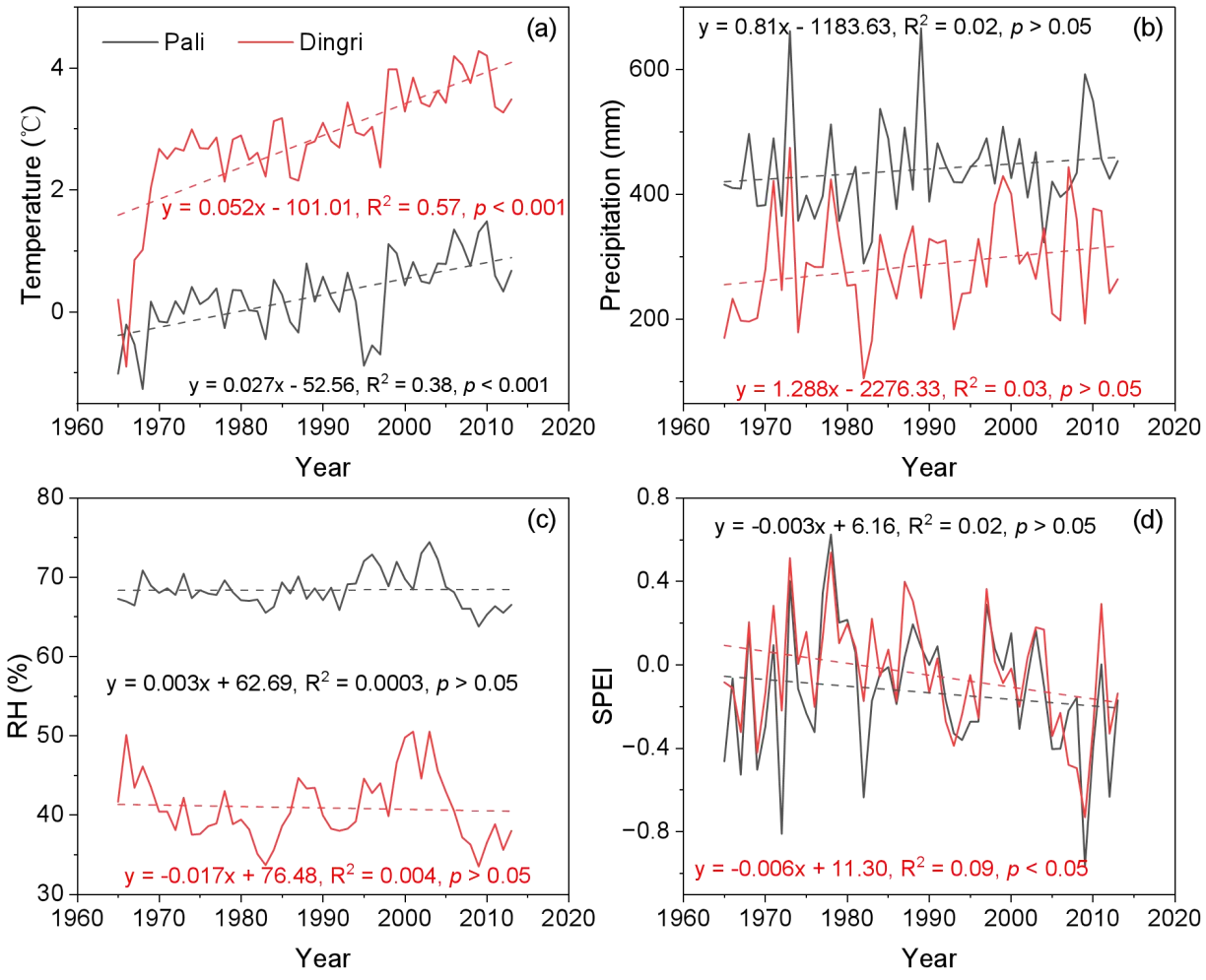

Figure S1. Temporal variations in climatic variables from the Dingri (28°38' N, 87°5' E, 4300 m) and Pali (27°44' N, 89°5' E, 4300 m) weather stations: (a) mean temperature, (b) total precipitation, (c) relative humidity (RH), and (d) standardized precipitation-evapotranspiration index (SPEI). The dashed lines depict linear regression models. The model statistics include the formula, coefficients of determination (R^2) and associated p-values.

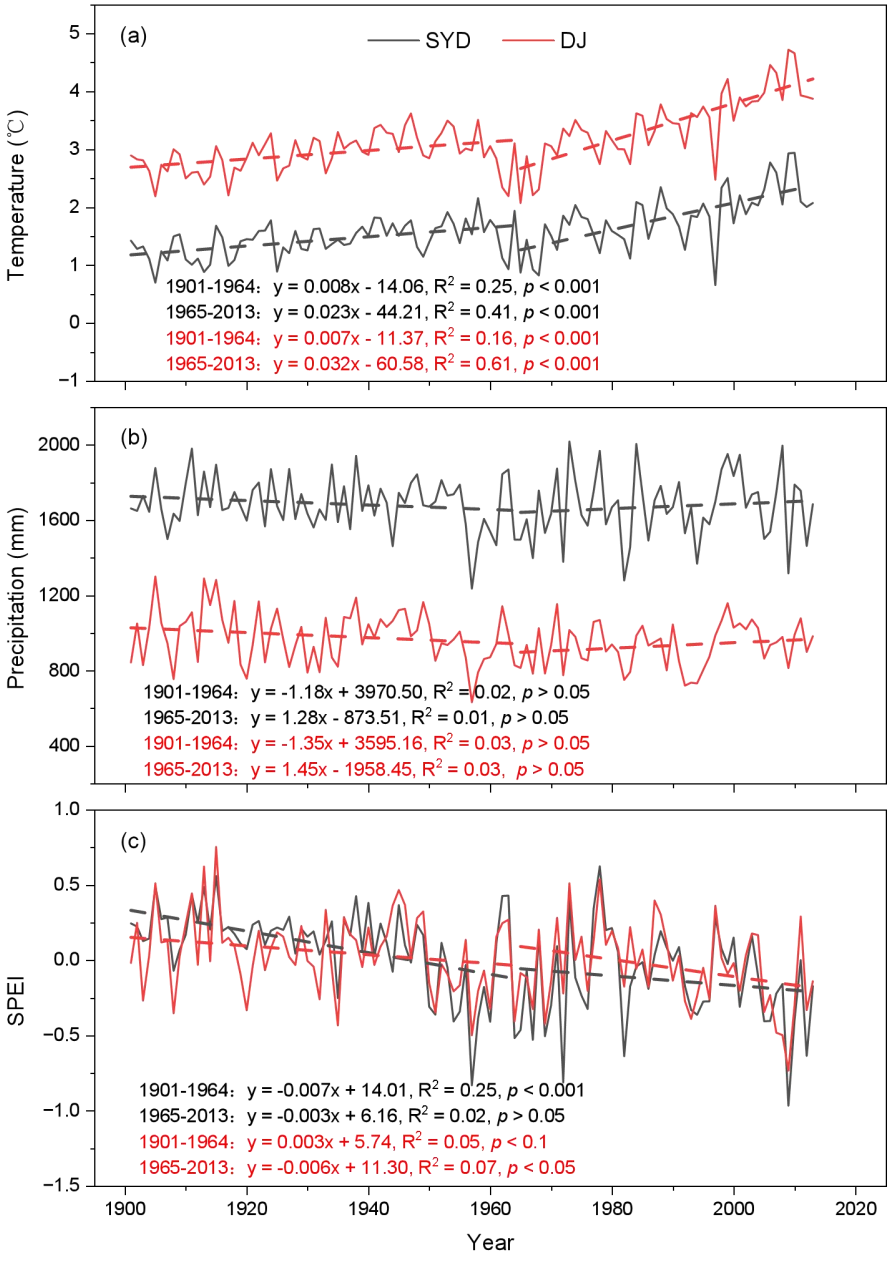

Figure S2. Temporal variations of mean temperature (a), total precipitation (b), SPEI (c) for the sampling sites based on the climate data extracted from the CRU TS 4.04 for the period 1901–2013. The dashed lines depict piecewise linear regression models, with a breakpoint at 1965. The model statistics include coefficient of determination (R^2) and associated p-values.

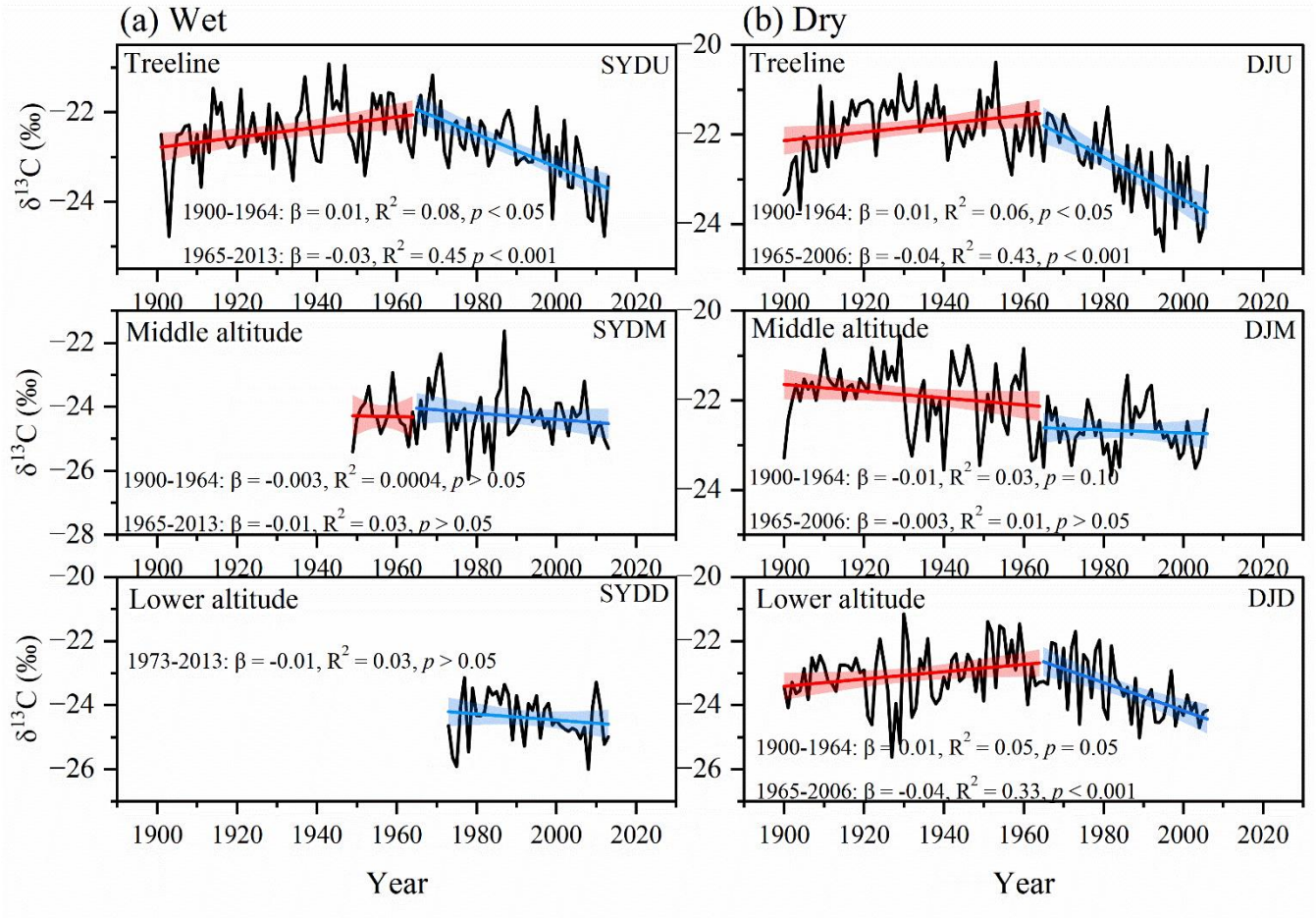

Figure S3. The temporal trends of tree-ring carbon isotope series for the study sites. The solid lines depict piecewise linear regression models, with a breakpoint at 1965. The model statistics include the slope of BAI (β, cm^2 $year^{-1}$), coefficient of determination (R^2) and associated p-values. The shaded regions denote 95% confidence intervals for the regression fits.

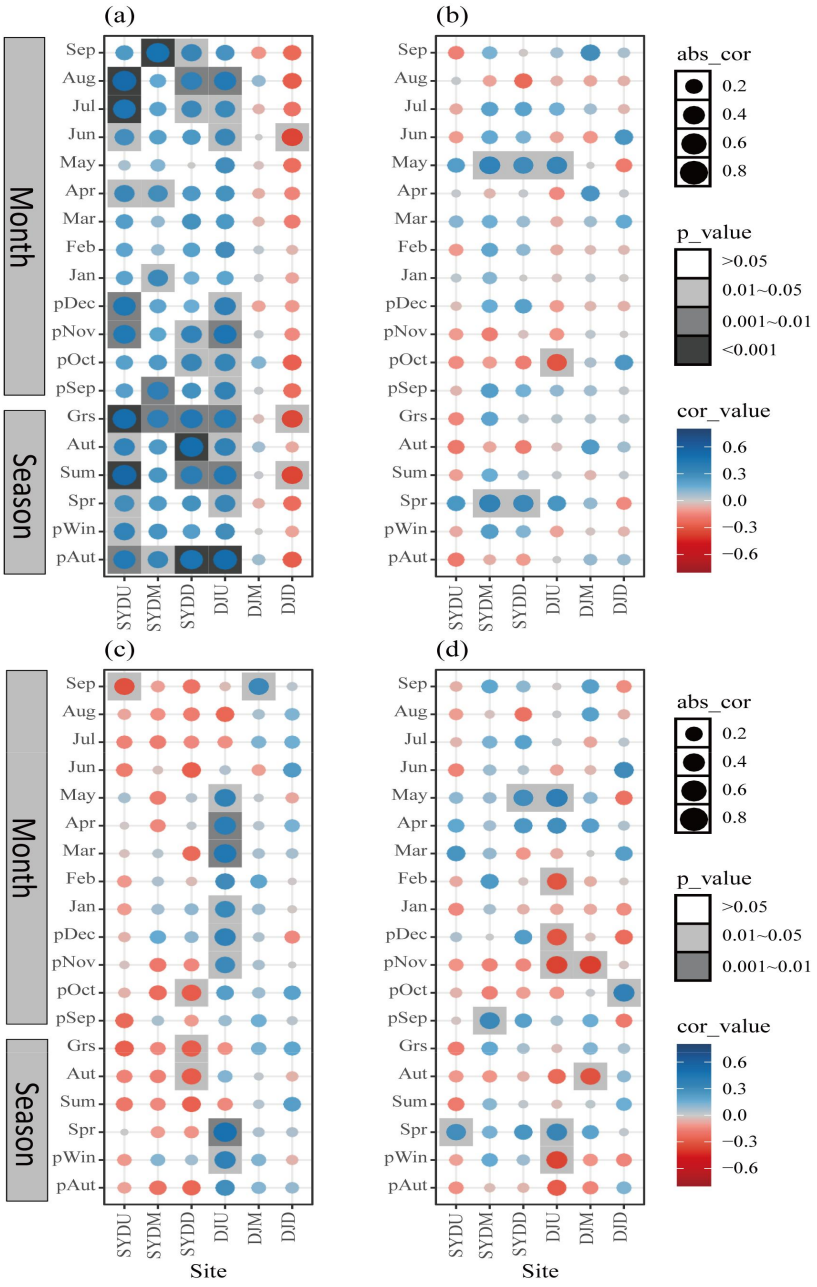

Figure S4. Pearson correlation coefficients between basal area increment (BAI) and climatic variables, including (a) mean temperature, (b) total precipitation, (c) relative humidity and (d) standardized precipitation-evapotranspiration index (SPEI), on both monthly and seasonal scales for Himalayan fir during the period 1965–2013. It should be noted that the BAI chronologies incorporated all dated core samples, not just those specifically selected for isotope analysis. "Grs" denotes the growing season (June to September). "Cor_value" and "abs_value" represent the correlation coefficient value and the absolute value of the correlation, respectively.

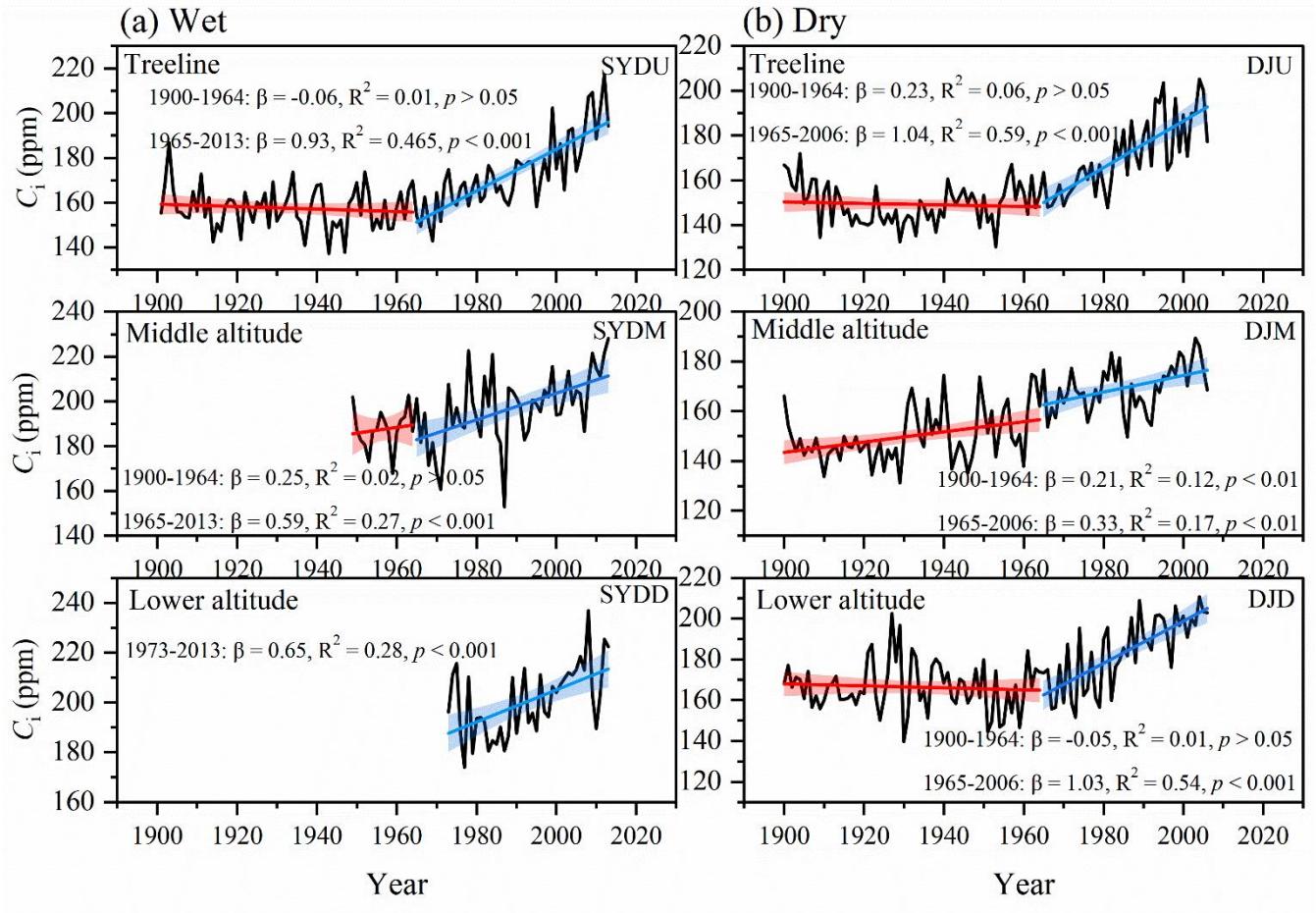

Figure S5. Temporal variation in physiological variables related to the regulation of tree leaf gas exchange, specifically intercellular CO_2 concentration (C_i). The solid lines depict piecewise linear regression models, with a breakpoint at 1965. The model statistics include the slope of BAI (β, cm^2 $year^{-1}$), coefficient of determination (R^2) and associated p-values. The shaded regions denote 95% confidence intervals for the regression fits.

Table S1. Information for the tree-ring samples on the southern Tibetan Plateau.

Position	Site	Species	Latitude (°N)	Longitude (°E)	Altitude (m)	Trees	DBH (cm)	Mean age	No. of stems/ha	TRW time span	rbar	MS
Treeline	SYDU	*ABSP*	27.506	88.99	4152	70	31.0±21.5	68	146	1784-2014	0.41	0.18
Middle altitude	SYDM	*ABSP*	27.515	88.99	3872	31	28.5±10.0	47	840	1837-2014	0.34	0.19
Lower altitude	SYDD	*ABSP*	27.516	88.99	3680	28	27.4±10.1	34	873	1938-2014	0.25	0.2
Treeline	DJU	*ABSP*	27.837	87.47	3918	19	25.0±5.8	132	344	1780-2006	0.40	0.17
Middle altitude	DJM	*ABSP*	27.838	87.46	3657	19	40.1±9.5	129	450	1774-2006	0.43	0.16
Lower altitude	DJD	*ABSP*	27.84	87.46	3378	13	28.3±6.6	85	556	1893-2006	0.37	0.18

ABSP, *Abies spectabilis*; rbar, the mean inter-series correlation; MS, mean sensitivity; DBH, diameter at breast height.

Table S2. Information for the tree-ring samples for isotope measurement on the southern Tibetan Plateau.

Position	Site	Species	Trees	TRW time span	Isotope data time span	Mean age	DBH (cm)	rbar	MS
Treeline	SYDU	*ABSP*	6	1784-2014	1901-2014	160	25.7±2.9	0.25	0.23
Middle altitude	SYDM	*ABSP*	5	1837-2014	1949-2014	90	28.7±4.9	0.25	0.24
Lower altitude	SYDD	*ABSP*	5	1938-2014	1973-2014	51	25.4±2.9	0.35	0.22
Treeline	DJU	*ABSP*	7	1780-2006	1888-2006	155	31.5±4.2	0.47	0.15
Middle altitude	DJM	*ABSP*	5	1774-2006	1869-2006	207	55.5±8.4	0.31	0.18
Lower altitude	DJD	*ABSP*	5	1893-2006	1897-2006	107	39.9±2.0	0.54	0.15

ABSP, *Abies spectabilis*; rbar, the mean inter-series correlation; MS, mean sensitivity; DBH, diameter at breast height.

Table S3. Summary of the piecewise structural equation meta-model (pSEM) for testing the influences of climatic factors on basal area increment (BAI) and intrinsic water-use efficiency (iWUE) of Himalayan fir during the period 1965–2010s at different sites.

Site	Response variable	Predictor variable	β	S.E.	Critical value	P-value
SYDU	BAI	iWUE	0.1166	0.0309	0.7472	0.4589
	BAI	Tgrs	0.1435	0.7033	0.8961	0.3751
	BAI	Tpaut	0.3777	0.2276	2.8362	<0.01
	BAI	Pgrs	-0.2081	0.0046	-1.556	0.1269
	iWUE	Tgrs	0.5308	2.7814	4.2362	<0.001
	iWUE	Tpaut	-0.0738	1.1135	-0.5724	0.5699
	iWUE	SPEIspr	0.1567	1.8069	1.2155	0.2305
SYDM	BAI	iWUE	0.2137	0.0703	1.4584	0.152
	BAI	Tgrs	0.2994	2.354	2.0129	<0.1
	BAI	Tpaut	0.1949	0.758	1.5834	0.1207
	BAI	Pgrs	0.1959	0.0156	1.5546	0.1274
	BAI	RHgrs	-0.2499	0.5443	-1.9459	<0.1
	iWUE	Tgrs	0.5562	4.2002	4.3683	<0.001
	iWUE	Tpaut	0.1356	1.5725	1.1065	0.2744
	iWUE	RHgrs	0.0315	1.1155	0.2491	0.8044
SYDD	BAI	iWUE	0.4527	0.0997	3.0971	<0.01
	BAI	Tgrs	0.2431	2.8764	1.7251	<0.1
	BAI	Tspr	0.161	1.1319	1.4095	0.1673
	BAI	Pspr	0.2083	0.0215	1.8744	<0.1
	iWUE	Tgrs	0.5507	3.7033	4.4483	<0.001
	iWUE	Tspr	0.2051	1.7453	1.7063	<0.1
	iWUE	RHgrs	-0.2113	0.9069	-1.7321	<0.1
DJU	BAI	iWUE	0.0256	0.0323	0.174	0.8628
	BAI	Tgrs	0.2596	0.379	1.659	0.1056
	BAI	Tspr	0.1989	0.2468	1.2472	0.2202
	BAI	RHspr	0.4223	0.0459	2.906	<0.01
	iWUE	Tgrs	-0.0401	2.0466	-0.216	0.8302
	iWUE	Tspr	0.3189	1.2732	1.7613	<0.1

	iWUE	RHspr	0.3172	0.2197	2.0745	<0.05
	iWUE	SPEIspr	0.2289	1.9737	1.363	0.1811
	BAI	iWUE	0.4975	0.0532	2.8913	<0.01
	BAI	Tgrs	-0.0034	0.8131	-0.0197	0.9844
	BAI	Tspr	-0.4129	0.4904	-2.5119	<0.05
DJM	BAI	RHspr	-0.5529	0.0866	-3.8923	<0.001
	BAI	Pspr	0.2686	0.0585	1.919	<0.1
	iWUE	Tgrs	0.442	2.2004	3.0331	<0.01
	iWUE	Tspr	0.271	1.4057	1.8595	<0.1
	BAI	iWUE	-0.1942	0.063	-1.5072	0.14
	BAI	Tgrs	-0.5024	0.7402	-3.9003	<0.001
DJD	BAI	RHwin	-0.2553	0.0577	-2.0357	<0.05
	iWUE	Tpaut	0.2125	1.3755	1.1598	0.2532
	iWUE	Tgrs	0.1124	2.1529	0.6132	0.5433

β is the standardized regression coefficient, and S.E. is the standard error. Abbreviations: Tpaut = previous autumn mean temperature; Tsum = summer mean temperature; Tspr = spring mean temperature; Tgrs = growing season mean temperature (June to September); RHspr = spring relative humidity; RHgrs = growing season relative humidity (June to September); RHwin = winter relative humidity; SPEIspr = spring standardized precipitation-evapotranspiration index; SPEIgrs = growing season standardized precipitation-evapotranspiration index (June to September).