Supplement of Hydrol. Earth Syst. Sci., 25, 3411–3427, 2021
https://doi.org/10.5194/hess-25-3411-2021-supplement

Hydrology and Earth System Sciences
Open Access
EGU

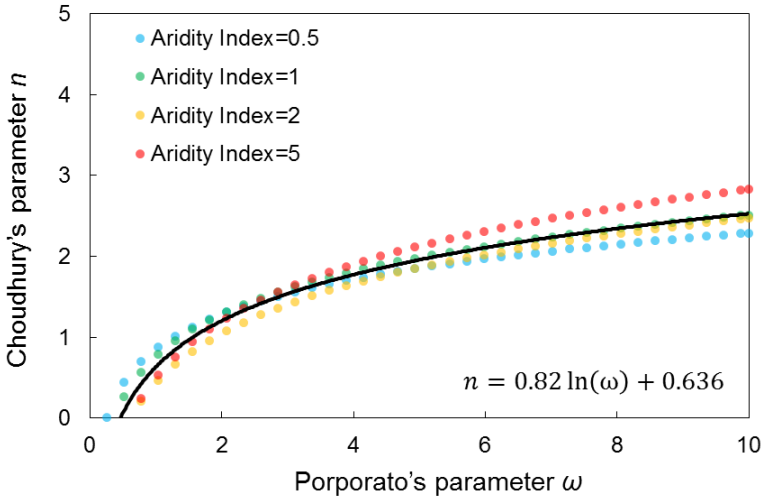
Supplement of

Low and contrasting impacts of vegetation CO_2 fertilization on global terrestrial runoff over 1982–2010: accounting for aboveground and belowground vegetation–CO_2 effects

Yuting Yang et al.

Correspondence to: Yuting Yang (yuting_yang@tsinghua.edu.cn)

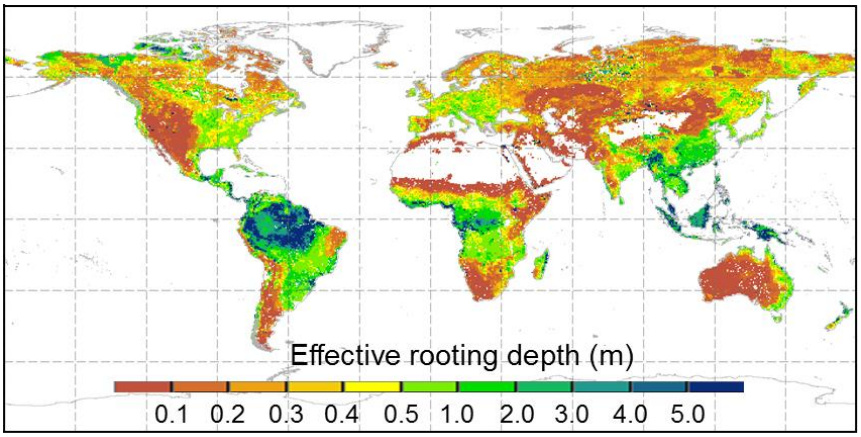
I. Relationship between Porporato's parameter ω and Chourhury's parameter n



Supplementary Figure S1 Relationship between Porporato's parameter ω and Chourhury's parameter n. The black solid curve represents the best fit relationship (R^2=0.96, p<0.001) provided by the equation given on the figure.

II. Global pattern of effective rooting depth

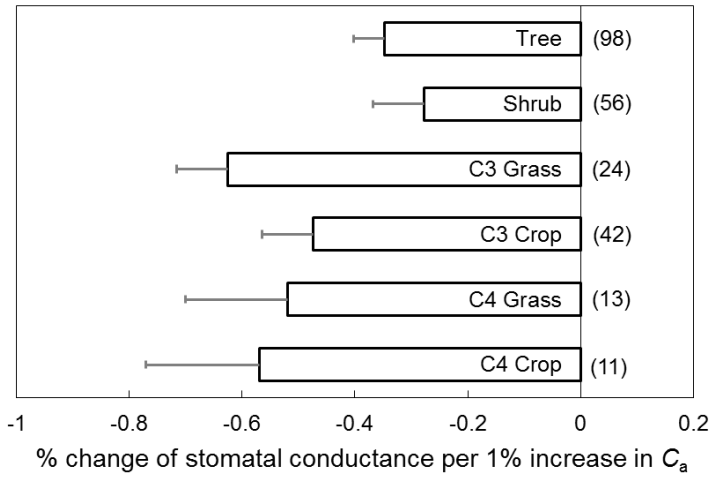
We estimated the effective rooting depth (Z_r) using an analytical carbon cost-benefit model based on ecosystem optimality theory (4). The climatological mean Z_r during 1982-2010 is shown in Supplementary Figure S2.



Supplementary Figure S2 Global pattern of mean annual effective rooting depth over 1982-2010.

V. Response of stomatal conductance to eCO_2

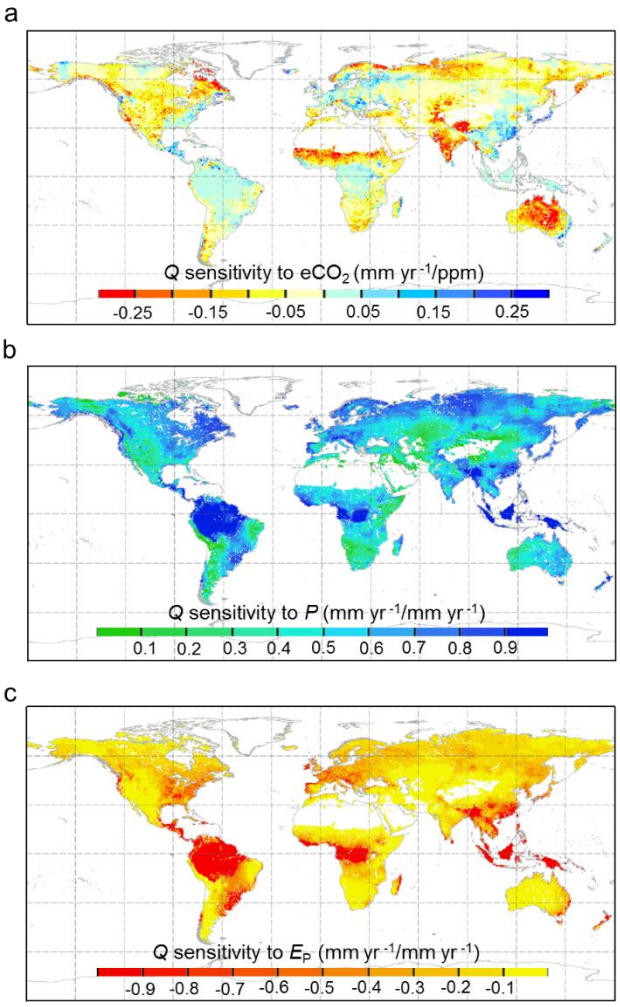
The response of stomatal conductance (g_s) to eCO_2 was determined using meta-analysis based on observations collected from 244 field experiments as summarized in *Ainsworth and Rogers* (5). As the magnitude of eCO_2 varies in these 244 experiments, we obtained the sensitivity of g_s to eCO_2 (percentage change in g_s per 1% increase in C_a) using linear interpolation. We then classified the 244 observations based on their biome type to construct a biome type-based look-up table of g_s sensitivity to eCO_2 (Supplementary Figure S3).



Supplementary Figure S3 Sensitivity of leaf-level stomatal conductance to eCO_2. Numbers in the brackets indicate the number of observations in each biome type. Error bars represent one standard deviation among individual observations.

VIII. Sensitivity of Q to eCO_2, P and E_P

In addition to showing the relative sensitivity of Q to eCO_2, P and E_P in the main text (Figure 7), here we also show the absolute sensitivity of Q to eCO_2, P and E_P (Supplementary Figure S4). Similar to the relative values, the absolute sensitivity of Q to eCO_2 is higher in dry regions and lower in wet areas (Supplementary Figure S8a). Regarding the absolute sensitivity of Q to P and E_P, both show a higher value in wet regions and smaller value in dry areas (Supplementary Figure S4b and c).



Supplementary Figure S4 Spatial distribution of the absolute sensitivity of Q to (a) eCO_2, (b) P and (c) E_P.

IX. Literature review of observed plant root characteristics in response to eCO_2

In the current study, we modeled the response of effective rooting depth (Z_r) to eCO_2 and found that Z_r increases with eCO_2 across the majority of global terrestrial ecosystems. However, it is impossible to directly validate our modeling result with field observations, as it is impossible to measure rooting depth across large regions. Here, we collected measured response of plant rooting characteristics (i.e., rooting depth and root biomass) to eCO_2 from 97 published observations (Supplementary Tables S1 and S2). Among these 97 observations, 86 (88.7%) reported an increased root length and/or root biomass as C_a rises. This is in consistent with our modeling results that eCO_2 generally increases the effective rooting depth (i.e., more roots, either in length or biomass). Since there is currently no large scale observations of rooting depth in response to eCO_2, the Supplementary Tables S1 and S2 provide an indirect, yet best available observational support for our modeling results.

Supplementary Table S1 Observed percentage changes (mean ± 1 standard deviation) in root characteristics (Δ root) in response to eCO_2. n is the number of observations and numbers in the brackets under column n indicates the number of observations showing increased root characteristics in response to eCO_2.

Root characteristics	Free-Air CO2 Enrichment			Open Top Chamber / Glasshouse		
	N	eCO_2 (%)	Δ root (%)	n	eCO_2 (%)	Δ root (%)
Total root Biomass	28 (26)	+52.6 ± 7.0	+34.6 ± 32.7	36 (32)	+91.3 ± 18.3	+38.0 ± 48.6
Total root length	1 (1)	+76.5	+38.8	3 (3)	+90.7 ± 6.9	+33.3 ± 12.5
Fine root biomass	24 (22)	+52.6 ± 8.6	+52.6 ± 35.4	15 (14)	+80.0 ± 25.8	+57.5 ± 52.1
Fine root length	4 (3)	+44.0 ± 7.6	+14.7 ± 11.3	3 (3)	+98.4 ± 1.5	+96.8 ± 74.4

Supplementary Table S2 Summary of observed root characteristics in response to elevation in atmospheric CO_2 concentration. *a*CO_2 in the ambient CO_2 concentration (ppm) and *e*CO_2 in the elevated CO_2 concentration (ppm). DRB is the dry root biomass; TRL is the total root length; DFRB is the dry fine root biomass; FRL is the fine root length. In the Method column, FACE represents Free-Air CO_2 Enrichment, OTC stands for open-top chamber and GH indicates glasshouse. Superscript 1 indicates root biomass in g m^{-2}, superscript 2 indicates root biomass in g per experimental unit, superscript 3 indicates root biomass in g per plant, superscript 4 indicates root length in mm cm^{-2}, superscript 5 indicates root length in m per plant. NR means not reported.

No.	Species	Location		CO_2 concentration (ppm)			DRB [a] or TRL [b]			DFRB [c] or FRL[d]			Method	Reference
		Latitude	*Longitude*	*a*CO_2	*e*CO_2	Increase	*a*CO_2	*e*CO_2	Change	*a*CO_2	*e*CO_2	Change		
1	*Pinus taeda L.*	35.97° N	79.08° W	363	563	200 (55%)	NR	NR	NR	238 [c,1]	325	+87 (36.5%)	FACE	Allen et al. (8)
2	*Calluna vulgaris, Deschampsia flexuosa*	55.88° N	8.68° E	380	510	130 (34.2%)	NR	NR	NR	47 [c,1]	71	+24 (51%)	FACE	Andresen et al. (9)
3	*Mixed forest*	47.47° N	7.5° E	380	550	170 (44.7%)	NR	NR	NR	290 [c,1]	256	-34 (-13.2%)	FACE	Bader et al. (10)
4	*A. capillaris*	53.22° N	4.13° W	340	680	340 (100%)	0.05 [a,3]	0.11	+0.06 (120%)	NR	NR	NR	OTC	Baxter et al. (11)
5	*P. alpine*	53.22° N	4.13° W	340	680	340 (100%)	0.45 [a,3]	0.55	+0.10 (22.2%)	NR	NR	NR	OTC	Baxter et al. (11)
6	*F. vivipara*	53.22° N	4.13° W	340	680	340 (100%)	5.2 [a,3]	2.80	-2.4 (-46.1%)	NR	NR	NR	OTC	Baxter et al. (11)
7	*Lolium perenne*	47.45° N	8.68° E	350	600	250 (71.4%)	1.125 [a,3]	1.25	+0.125 (11.1%)	NR	NR	NR	FACE	Bazot et al. (12)
8	*Sweet potato*	35.78° N	78.68° W	364	666	302 (83%)	59.28 [a,3]	83.18	+23.9 (40.3%)	NR	NR	NR	OTC	Bhattacharya et al. (13)
9	*Scrub-Oak*	28.63° N	80.7° W	363	726	363 (100%)	737 [a,1]	498	-239 (32.4%)	NR	NR	NR	OTC	Brown et al. (14)
10	*P.alba*	42.37° N	11.8° E	370	550	180 (48.6%)	758 [a,1]	1046	+288 (38%)	265 [c,1]	478	+2.13 (80.4%)	FACE	Calfapietra et al. (15)
11	*P.nigra*	42.37° N	11.8° E	370	550	180 (48.6%)	844 [a,1]	1030	+186 (22%)	273 [c,1]	387	+1.14 (41.8%)	FACE	Calfapietra et al. (15)

12	*P.× euramericana*	42.37° N	11.8° E	370	550	180 (48.6%)	787 [a,1]	1011	+224 (28.5%)	295 [c,1]	446	+1.51 (51.2%)	FACE	Calfapietra et al. (15)
13	*Mixed grasses*	41.18° N	104.9° W	383	600	217 (56.7%)	NR	NR	NR	303.4 [c,1]	319	+15.6 (5.1%)	FACE	Carrillo et al. (16)
14	*Prunus persica*	55.87° N	3.2° W	350	700	350 (100%)	15.8 [a,3]	19.8	+4 (25.3%)	NR	NR	NR	OTC	Centritto et al. (17)
15	*Scots Pine*	51.12° N	0.83° W	350	700	350 (100%)	NR	NR	+50% [a,3]	NR	NR	NR	OTC	Crookshanks et al. (18)
16	*Ash*	51.12° N	0.83° W	350	700	350 (100%)	131.3 [a,3]	133.3	+2.0 (1.5%)	30.75 [c,3]	39.25	+8.5 (27.6%)	OTC	Crookshanks et al. (18)
17	*Oak*	51.12° N	0.83° W	350	700	350 (100%)	106.9 [a,3]	133.7	+26.8 (25.1%)	8.75 [c,3]	20.12	+11.37 (130%)	OTC	Crookshanks et al. (18)
18	*Mixed grasses*	45.4° N	93.18° W	378	560	182 (48.1%)	580 [a,1]	715	+135 (23.3%)	410 [c,1]	520	+110 (26.8%)	FACE	Crous et al. (19)
19	*Mixed forbs*	45.4° N	93.18° W	378	560	182 (48.1%)	145 [a,1]	170	+25 (17.2%)	80 [c,1]	125	+45 (56.3%)	FACE	Crous et al. (19)
20	*Oak-palmetto*	28.63° N	80.7° W	350	700	350 (100%)	NR	NR	NR	NR	NR	+63.2% [d,4]	OTC	Day et al. (20)
21	*Sorghum*	33.07° N	111.97° W	373	566	193 (51.7%)	134 [a,1]	161	+27 (20.1%)	NR	NR	NR	FACE	Derner et al. (21)
22	*Cotton*	33.07° N	111.97° W	373	566	193 (51.7%)	41 [a,1]	74.5	+33.5 (81.7%)	NR	NR	NR	FACE	Derner et al. (21)
23	*Quercus myrtifolia* Wasd.	28.63° N	80.7° W	363	713	350 (96.4%)	NR	NR	NR	7 [d,4]	21	+14 (200%)	OTC	Dilustro et al. (22)
24	*Ambrosia*	36.82° N	115.75° W	374	511	137 (36.6%)	NR	NR	NR	14.9 [d,4]	14.6	-0.3 (-0.2%)	FACE	Ferguson et al. (23)
25	*Larrea*	36.82° N	115.75° W	374	511	137 (36.6%)	NR	NR	NR	20.6 [d,4]	22.3	+1.7 (8.3%)	FACE	Ferguson et al. (23)
26	*Mixed grasses*	54.17° N	2.78° W	350	600	250 (71.4%)	2970 [a,1]	4390	+1420 (48%)	NR	NR	NR	OTC	Fitter et al. (24)
27	*Pinus taeda L.*	35.97° N	79.15° W	334	534	200 (59.9%)	NR	NR	NR	363.5 [c,1]	385.4	+21.9 (6%)	FACE	George et al. (25)
28	*Sweetgum*	35.97° N	79.15° W	345	545	200 (58%)	NR	NR	NR	112.6 [c,1]	194.8	+82.8 (73%)	FACE	George et al. (25)
29	*Larix decidua*	46.77° N	9.87° E	370	576	206 (55.7%)	NR	NR	NR	240.5 [c,1]	221.5	-19 (-7.9%)	FACE	Handa et al. (26)
30	*Pinus uncinata*	46.77° N	9.87° E	370	576	206 (55.7%)	NR	NR	NR	261.5 [c,1]	463	+201.5 (77.1%)	FACE	Handa et al. (26)
31	*Mixed grasses*	37.67° N	122.37° W	370	680	310 (83.8%)	NR	NR	NR	185 [c,1]	405	+220 (118.9%)	FACE	Henry et al. (27)
32	*Mixed grasses*	37.4° N	122.22° W	360	720	360 (100%)	36 [a,1]	48	+12 (33.3%)	NR	NR	NR	OTC	Higgins et al. (28)
33	*Lolium perenne*	47.45° N	8.68° E	350	600	250 (71.4%)	6 [a,3]	10.5	+4.5 (75%)	NR	NR	NR	FACE	Hill et al. (29)

34	*Luzula*	46.57° N	8.42° E	385	580	195 (50.6%)	4.2 [a,2]	4.4	+0.2 (4.8%)	NR	NR	NR	FACE	Inauen et al. (30)
35	*Poa*	46.57° N	8.42° E	385	580	195 (50.6%)	0.72 [a,2]	0.73	+0.01 (1.4%)	NR	NR	NR	FACE	Inauen et al. (30)
36	*Ranunculus*	46.57° N	8.42° E	385	580	195 (50.6%)	1.1 [a,2]	0.98	-0.12 (-10.9%)	NR	NR	NR	FACE	Inauen et al. (30)
37	*Veronica*	46.57° N	8.42° E	385	580	195 (50.6%)	0.8 [a,2]	0.82	+0.02 (2.5%)	NR	NR	NR	FACE	Inauen et al. (30)
38	*Sweetgum*	35.9° N	84.33° W	380	560	180 (50%)	NR	NR	NR	209 [c,1]	437	+228 (109%)	FACE	Iverson et al. (31)
39	*Pinus sylvestris L.*	51.22° N	4.41° E	350	750	400 (114%)	130.2 [a,2]	328.5	+198.3 (152%)	13.0 [c,2]	29.6	+16.6 (128%)	OTC	Jach et al. (32)
40	*Loblolly pine forest*	35.97° N	79.083° W	370	570	200 (54%)	NR	NR	NR	248 [c,1]	307	+59 (23.8%)	FACE	Jackson et al. (33)
41	*Pinus sylvestris L.*	51.17° N	4.4° E	350	700	350 (100%)	81.7 [a,3]	184.6	+102.9 (126%)	22 [c,3]	50	+28 (127%)	OTC	Janssens et al. (34)
42	*Mixed grasses*	39.2° N	96.58° W	353	706	353 (100%)	1038 [a,1]	1430	+392 (37.7%)	327 [a,1]	489	+162 (49.5%)	OTC	Jastrow et al. (35)
43	*Lolium perenne, Trifolium repens*	35.97° N	79.08° W	340	600	260 (76.5%)	1020 [b,5]	1410	+390 (38.8%)	NR	NR	NR	FACE	Jongen et al. (36)
44	*Pinus sylvestris L.*	35.97° N	79.083° W	360	720	360 (100%)	NR	NR	NR	NR	NR	+39.9% [c,1]	OTC	Kasurinen et al. (37)
45	*Citrus aurantium L.*	33.42° N	112.1° W	360	760	300 (83.3%)	65 [b,4]	82.3	+17.3 (26.6%)	NR	NR	NR	OTC	Kimball et al. (38)
46	*Wheat*	33.07° N	111.98° W	358	550	192 (53.6%)	NR	NR	+17% [a,1]	NR	NR	NR	FACE	Kimball et al. (39)
47	*Trembling aspen*	45.55° N	84.78° W	360	560	200 (55.6%)	NR	NR	NR	72 [c,1]	124	+52 (72.2%)	OTC	King et al. (40)
48	*Sugar maple*	45.55° N	84.78° W	360	560	200 (55.6%)	NR	NR	NR	142 [c,1]	143	+1 (0.7%)	OTC	King et al. (40)
49	*Aspen*	45.68° N	89.63° W	346	547	201 (58.1%)	NR	NR	NR	261 [c,1]	555	+294 (113%)	FACE	King et al. (41)
50	*Aspen--birth*	45.68° N	89.63° W	346	547	201 (58.1%)	NR	NR	NR	173 [c,1]	317	+144 (83%)	FACE	King et al. (41)

51	*Mixed grasses*	40.85° N	104.72° W	360	720	360 (100%)	920 [a,1]	1030	+110 (12%)	NR	NR	NR	OTC	King et al. (42)
52	*Wheat*	32.6° N	119.7° E	378	578	200 (52.9%)	90.7 [a,1]	96.7	+6 (6.6%)	NR	NR	NR	FACE	Kou et al. (43)
53	*Acacia floribunda*	33.77° S	151.11° E	390	550	160 (41%)	89.5 [a,1]	95.6	+6.1 (6.8%)	33.7 [c,1]	36.0	+2.3 (7.1%)	GH	Lawson et al. (44)
54	*Casuarina cunninghamiana*	33.77° S	151.11° E	390	550	160 (41%)	91.9 [a,1]	172.7	+80.8 (87.9%)	26.3 [c,1]	65.2	+38.9 (147.5%)	GH	Lawson et al. (44)
55	*Eucalyptus camaldulensis*	33.77° S	151.11° E	390	550	160 (41%)	235.7 [a,1]	227.3	-8.4 (0.36%)	41.9 [c,1]	27.5	-14.4 (-34.5%)	GH	Lawson et al. (44)
56	*P. alba*	42.37° N	11.8° E	370	550	180 (48.6%)	NR	NR	+19% [a,1]	NR	NR	NR	FACE	Liberloo et al. (45)
57	*P. nigra*	42.37° N	11.8° E	370	550	180 (48.6%)	NR	NR	+28% [a,1]	NR	NR	NR	FACE	Liberloo et al. (45)
58	*P. ×euramericana*	42.37° N	11.8° E	370	550	180 (48.6%)	NR	NR	+48% [a,1]	NR	NR	NR	FACE	Liberloo et al. (45)
59	*P. alba*	42.62° N	11.81° E	370	550	180 (48.6%)	NR	NR	+47% [a,1]	NR	NR	+35% [c,1]	FACE	Lukac et al. (46)
60	*P. nigra*	42.62° N	11.81° E	370	550	180 (48.6%)	NR	NR	+76% [a,1]	NR	NR	+84% [c,1]	FACE	Lukac et al. (46)
61	*P. × euramericana*	42.62° N	11.81° E	370	550	180 (48.6%)	NR	NR	+71% [a,1]	NR	NR	+53% [c,1]	FACE	Lukac et al. (46)
62	*Pine tree*	35.97° N	70.09° W	365	565	200 (54.8%)	NR	NR	NR	79.8 [c,1]	134.2	+54.4 (68.2%)	FACE	Matamala et al. (47)
63	*Mixed grass and shrub*	40.82° N	104.77° W	360	720	360 (100%)	1.31 [b,4]	1.98	+0.67 (50.8%)	NR	NR	NR	OTC	Milchunas et al. (48)
64	*Pinus echinata seedlings*	35.93° N	84.31° W	368	695	327 (88.9%)	1.92 [a,3]	2.71	+0.79 (41%)	1.00 [c,3]	1.52	+0.52 (52%)	OTC	Norby et al. (49)
65	*Sweetgum*	35.9° N	84.33° W	368	537	169 (45.9%)	254 [a,1]	491	+237 (93.3%)	240 [c,1]	375	+135 (56.3%)	FACE	Norby et al. (50)
66	*Mixed grasses*	39.2° N	96.58° W	357	714	357 (100%)	181 [a,1]	249	+68 (37.6%)	NR	NR	NR	OTC	Owensby et al. (51)
67	*Rice*	31.62° N	120.47° E	375	575	200 (53.3%)	NR	NR	+66% [a,2]	NR	NR	NR	FACE	Pang et al. (52)
68	*Mixed grasses*	40.67° N	104.75° W	360	720	360 (100%)	842 [a,1]	972	+130 (15.4%)	NR	NR	NR	OTC	Pendall et al. (53)

69	*Mixed grasses*	42.7° S	147.27° E	372	549	177 (47.6%)	653 [a,1]	429	-224 (-34.3%)	NR	NR	NR	FACE	Pendall et al. (54)
70	*Pinus ponderosa Dougl. Ex Laws.*	35.97° N	79.08° W	420	690	270 (64%)	NR	NR	NR	485.6 [c,1]	563.5	+77.9 (16%)	OTC	Phillips et al. (55)
71	*Aspen*	45.67° N	89.63° E	356	534	178 (50%)	NR	NR	NR	171 [c,1]	230	+59 (34.5%)	FACE	Pregitzer et al. (56)
72	*Populus*	45.57° N	84.67° W	345	693	348 (101%)	193.3 [a,3]	270	+76.7 (39.7%)	18.3 [c,3]	27.2	+8.9 (48.6%)	OTC	Pregitzer et al. (57)
73	*Populus termuloides*	45.58° N	84.7° W	357	707	350 (98%)	NR	NR	NR	79.8 [c,1]	121	+41.2 (51.6%)	OTC	Pregitzer et al. (58)
74	*Cotton*	33.07° N	111.98° W	370	550	180 (48.6%)	NR	NR	NR	1.73 [d,5]	2.11	+0.38 (22%)	FACE	Prior et al. (59)
75	*Longleaf pine savannahs*	32.1° N	85.08° W	365	720	355 (97.3%)	106.5 [a,1]	115.6	+9.1 (8.5%)	NR	NR	NR	OTC	Pritchard et al. (60)
76	*Red maple, winged elm, sweetgum*	36.15° N	79.97° W	365	565	200 (54.8%)	181.1 [a,1]	228.6	+47.5 (26.2%)	NR	NR	NR	FACE	Pritchard et al. (61)
77	*Pinus taeda L.*	35.97° N	79.08° W	368	567	199 (54%)	NR	NR	NR	NR	NR	+28.6% [d,4]	FACE	Pritchard et al. (62)
78	*Winter wheat*	37.88° N	114.68 ° E	358	712	354 (98.9%)	NR	NR	NR	1210 [d,4]	1540	+330 (27.3%)	OTC	Qiao et al. (63)
79	*Phaseolus vulgaris*	55.52° N	3.2° W	350	700	350 (100%)	4.02 [a,3]	4.75	+0.73 (18.2%)	NR	NR	NR	OTC	Radoglou & Jarvis (64)
80	*Birch tree*	55.52° N	3.2° W	350	700	350 (100%)	470 [a,1]	1040	+570 (121%)	200 [c,1]	480	+280 (140%)	OTC	Rey & Jarvis (65)
81	*Wheat*	55.68° N	12.2° E	360	680	320 (88.9%)	17.8 [b,4]	21.8	+4 (22.5%)	NR	NR	NR	OTC	Ronn et al. (66)
82	*Pinus*	32.62° N	85.48° W	365	720	355 (97.3)	1000 [a,1]	1800	+800 (80%)	NR	NR	NR	OTC	Runion et al. (67)
83	*Quercus*	32.62° N	85.48° W	365	720	355 (97.3)	145 [a,1]	165	+20 (13.8%)	NR	NR	NR	OTC	Runion et al. (67)
84	*Aristida*	32.62° N	85.48° W	365	720	355 (97.3)	190 [a,1]	130	-60 (-31.6%)	NR	NR	NR	OTC	Runion et al. (67)
85	*Asclepias*	32.62° N	85.48° W	365	720	355 (97.3)	6.4 [a,1]	3.2	-3.2 (-50%)	NR	NR	NR	OTC	Runion et al. (67)

86	*Crotalaria*	32.62° N	85.48° W	365	720	355 (97.3)	1.9 [a,1]	1.2	-0.7 (-36.8%)	NR	NR	NR	OTC	Runion et al. (67)
87	*Pigeon pea*	28.58° N	77.2° E	387	580	193 (49.9%)	450 [a,1]	600	+150 (33.3%)	NR	NR	NR	OTC	Saha et al. (68)
88	*Mixed grasses*	46.58° N	8.38° E	355	680	325 (91.5%)	80 [a,1]	84.4	+4.4 (5.5%)	NR	NR	NR	OTC	Schappi & Korner (69)
89	*Lolium perenne*	47.45° N	8.68° E	360	600	240 (66.7%)	184 [a,1]	384	+200 (109%)	NR	NR	NR	FACE	Suter et al. (70)
90	*Pinus radiata D. Don*	43.53° S	172.7° E	350	650	300 (85.7%)	NR	NR	NR	NR	NR	+36% [c,1]	OTC	Thomas et al. (71)
91	*Phalaris swards*	35.37° S	149.22° E	375	750	375 (100%)	NR	NR	NR	400 [c,1]	465	+65 (16.3%)	OTC	Volder et al. (72)
92	*Acer rubrum L., Acer saccharum Marsh.*	35.9° N	84.33° W	364	664	300 (82.4%)	NR	NR	NR	NR	NR	+122% [c,1]	OTC	Wan et al. (73)
93	*Birch tree*	55.95° N	3.22° W	350	700	350 (100%)	315.5 [a,3]	511	+195.5 (62%)	110 [c,3]	251	+141 (128%)	OTC	Wang et al. (74)
94	*Mixed grasses*	47.45° N	8.68° E	358	598	240 (67%)	0.48 [a,2]	0.78	+0.3 (62.5%)	NR	NR	NR	FACE	Warwick et al. (75)
95	*Red spring wheat*	33.12° N	111.15° W	370	550	180 (48.6%)	88.8 [a,1]	104.2	+15.4 (17.3%)	NR	NR	NR	FACE	Wechsung et al. (76)
96	*P. tremuloides*	45.57° N	84.67° W	357	707	350 (98%)	3110 [a,2]	4245	+1135 (36.5%)	555 [c,2]	750	+195 (35.1%)	OTC	Zak et al. (77)
97	*Cirsium arvense*	39.03° N	76.9° W	419	762	343 (81.9%)	0.335 [a,2]	0.825	+0.49 (146%)	NR	NR	NR	OTC	Ziska et al. (78)

7

References in Supporting Information

1. Nemani, R. R. *et al*. Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999. *Science* **300**, 1560-1563 (2003).
2. Budyko, M. I. Climate and life. (Academic, New York, 1974).
3. Yang, Y., Randall, R. J., McVicar, T. R. & Roderick, M. L. An analytical model for relating global terrestrial carbon assimilation with climate and surface conditions using a rate limitation framework. *Geophys. Res. Lett*. **42**, 9825-9835.
4. Guswa, A. J. The influence of climate on root depth: A carbon cost-benefit analysis. *Water Resour. Res*. **44**, WR006384 (2008).
5. Ainsworth, E. A. & Rogers, A. The response of photosynthesis and stomatal conductance to rising [CO_2]: mechanisms and environmental interactions. *Plant, Cell Environ*. **30**, 258-270 (2007).
6. Zhang, Y. *et al*. Multi-decadal trends in global terrestrial evapotranspiration and its components. *Sci. Rep.* **6**, 19124 (2006).
7. Jung, M. *et al*. Global patterns of land-atmosphere fluxes of carbon dioxide, latent heat, and sensible heat derived from eddy covariance, satellite, and meteorological observations. *J. Geophys. Res. Biogeosci.* **116**, JG001566 (2011).
8. Allen, A.S., Andrews, J.A., Finzi, A.C., Matamala, R., Richter, D.D. & Schlesinger, W.H. Effects of free-air CO_2 enrichment (FACE) on belowground processes in a *Pinus taeda* forest. *Ecol. Appl.* **10**, 437-448 (2000).
9. Andresen, L.C., Michelsen, A., Ambus, P. & Beier, C. Belowground heathland responses after 2 years of combined warming, elevated CO_2 and summer drought. *Biogeochemistry* **101**, 27-42 (2010).
10. Bader, M., Hiltbrunner, E. & Korner, C. Fine root responses of mature deciduous forest trees to free air carbon dioxide enrichment (FACE). *Funct. Ecol.* **23**, 913-921 (2009).
11. Baxter, R., Ashenden, T.W., Sparks, T.H. & Farrar, J.F. Effects of elevated carbon dioxide on three montane grass species. I. Growth and dry matter partitioning. *J. Exp. Bot.* **45**, 305-315 (1994).

12. Bazot, S., Ulff, L., Blum, H., Nguyen, C. & Robin, C. Effects of elevated CO_2 concentration on rhizodeposition from *Lolium perenne* grown on soil exposed to 9 years of CO_2 enrichment. *Soil Biol. Biochem.* **38**, 729-736 (2006).
13. Bhattacharya N.C., *et al*. Interaction of enriched CO_2 and water stress on the physiology of and biomass production in sweet potato grown in open-top chambers. *Plant Cell Environ.* **13**, 933-940 (1990).
14. Brown, A.L.P., Day, F.P. & Stover, D.B. Fine root biomass estimates from minirhizotron imagery in a shrub ecosystem exposed to elevated CO_2. *Plant and Soil* **317**, 145-153 (2009).
15. Calfapietra, C. *et al.* (2003) Free-air CO_2 enrichment (FACE) enhances biomass production in a short-rotation poplar plantation. *Tree Physiol.* **23**, 805-814 (2003).
16. Carrillo, Y., Pendall, E., Dijkstra, F.A., Morgan, J.A. & Newcomb, J.M. Response of soil organic matter pools to elevated CO_2 and warming in a semi-arid grassland. *Plant and Soil* **347**, 339-350 (2011).
17. Centritto, M. The effects of elevated CO_2 and water availability on growth and physiology of peach (*Prunus persica*) plants. *Plant Biosyst.* **136**, 177-188 (2002).
18. Crookshanks, M., Taylor, G. & Broadmeadow, M. Elevated CO_2 and tree root growth: contrasting responses in *Fraxinus excelsior*, *Quercus petraea* and *Pinus sylvestris*. *New Phytol.* **138**, 241-250 (1998).
19. Crous, K.Y., Reich, P.B., Hunter, M.D. & Ellsworth, D.S. Maintenance of leaf N controls the photosynthetic CO_2 response of grassland species exposed to 9 years of free-air CO_2 enrichment. *Global Change Biol.* **16**, 2076-2088 (2010).
20. Day, F.P., Weber, E.P., Hinkle, C.R. & Drake, B.G. Effects of elevated atmospheric CO_2 on fine root length and distribution in an oak-palmetto scrub ecosystem in central Florida. *Global Change Biol.* **2**, 143-148 (1996).
21. Derner, J.D. *et al.* (2003) Above- and below-ground responses of C_3-C_4 species mixtures to elevated CO_2 and soil water availability. *Global Change Biol.* **9**, 452-460 (2003).

22. Dilustro, J.J., Day, F.P., Drake, B.G. & Hinkle, C.R. Abundance, production and mortality of fine roots under elevated atmospheric CO_2 in an oak-scrub ecosystem. *Environ. Exper. Bot.* **48**, 149-159 (2002).
23. Ferguson, S.D. & Nowak, R.S. Transitory effects of elevated atmospheric CO_2 on fine root dynamics in an arid ecosystem do not increase long-term soil carbon input from fine root litter. *New Phytol.* **190**, 953-967 (2011).
24. Fitter, A.H. *et al*. Root production and turnover and carbon budgets of two contrasting grasslands under ambient and elevated atmospheric carbon dioxide concentrations. *New Phytol.* **137**, 247-255 (1997).
25. George, K., Norby, R.J., Hamilton, J.G. & Delucia, E.H. Fine-root respiration in a loblolly pine and sweetgum forest growing in elevated CO_2. *New Phytol.* **160**, 511-522 (2003).
26. Handa, I.T., Hagedorn, F. & Hattenschwiler, S. No stimulation in root production in response to 4 years of *in situ* CO_2 enrichment at the Swiss treeline. *Funct. Ecol.* **22**, 348-358 (2008).
27. Henry, H., Chiariello, N.R., Vitousek, P.M., Mooney, H.A. & Field, C.B. Interactive effects of fire, elevated carbon dioxide, nitrogen deposition, and precipitation on a California annual grassland. *Ecosystems* **9**, 1066-1075 (2006).
28. Higgins, P., Jackson, R.B., Des Rosiers, J.M. & Field, C.B. Root production and demography in a california annual grassland under elevated atmospheric carbon dioxide. *Global Change Biol.* **8**, 841-850 (2002).
29. Hill, P.W. *et al.* The fate of photosynthetically-fixed carbon in *Lolium perenne* grassland as modified by elevated CO_2 and sward management. *New Phytol.* **173**, 766-777 (2007).
30. Inauen, N., Körner, C. & Hiltbrunner, E. No growth stimulation by CO_2 enrichment in alpine glacier forefield plants. *Global Change Biol.* **18**, 985-999 (2012).
31. Iversen, C.M., Ledford, J., Norby, R.J. CO_2 enrichment increases carbon and nitrogen input from fine roots in a deciduous forest. *New Phytol.* **179**, 837-847

(2008).

32. Jach, M.E., Laureysens, I., Ceulemans, R. Above- and below-ground production of young Scots pine (*Pinus sylvestris* L.) trees after three years of growth in the field under elevated CO_2. *Ann. Bot.* **85**, 789-798 (2000).
33. Jackson, R.B., Cook, C.W., Pippen, J.S. & Palmer, S.M. Increased belowground biomass and soil CO_2 fluxes after a decade of carbon dioxide enrichment in a warm-temperate forest. *Ecology* **90**, 3352-3366 (2009).
34. Janssens, I.A., Crookshanks, M., Taylor, G. & Ceulemans, R. Elevated atmospheric CO_2 increases fine root production, respiration, rhizosphere respiration and soil CO_2 efflux in Scots pine seedlings. *Global Change Biol.* **4**, 871-878 (1998).
35. Jastrow, J.D., Miller, R.M. & Owensby, C.E. Long-term effects of elevated atmospheric CO_2 on below-ground biomass and transformations to soil organic matter in grassland. *Plant and Soil* **224**, 85-97 (2000).
36. Jongen, M., Jones, M.B., Hebeisen, T., Blum, H. & Hendrey, G. The effects of elevated CO_2 concentrations on the root growth of *Lolium perenne* and *Trifolium repens* grown in a FACE system. *Global Change Biol.* **1**, 361-371 (1995).
37. Kasurinen, A., Keinanen, M.M., Kaipainen, S., Nilsson, L.O., Vapaavuori, E., Kontro, M.H. & Holopainen, T. Below-ground responses of silver birch trees exposed to elevated CO_2 and O_3 levels during three growing seasons. *Global Change Biol.* **11**, 1167-1179 (2005).
38. Kimball, B.A., Idso, S.B., Johnson, S. & Rillig, M.C. Seventeen years of carbon dioxide enrichment of sour orange trees: final results. *Global Change Biol.* **13**, 2171-2183 (2007).
39. Kimball, B.A. *et al.* Productivity and water use of wheat under free-air CO_2 enrichment. *Global Change Biol.* **1**, 429-442 (1995).
40. King, J.S., Pregitzer, K.S., Zak, D.R., Holmes, W.E. & Schmidt, K. Fine root chemistry and decomposition in model communities of north-temperate tree species show little response to elevated atmospheric CO_2 and varying soil

resource availability. *Oecologia* **146**, 318-328 (2005).

41. King, J.S. *et al.* Fine-root biomass and fluxes of soil carbon in young stands of paper birch and trembling aspen as affected by elevated atmospheric CO_2 and tropospheric O_3. *Oecologia* **128**, 237-250 (2001).
42. King, J.Y., Mosier, A.R., Morgan, J.A., Lecain, D.R., Milchunas, D.G. & Parton, W.J. Plant nitrogen dynamics in shortgrass steppe under elevated atmospheric carbon dioxide. *Ecosystems* **7**, 147-160 (2004).
43. Kou, T.J., Zhu, J.G., Xie, Z.B., Hasegawa, T. & Heiduk, K. Effect of elevated atmospheric CO_2 concentration on soil and root respiration in winter wheat by using a respiration partitioning chamber. *Plant and Soil* **299**, 237-249 (2007).
44. Lawson, J.R., Fryirs, K.A. & Leishman, M.R. Interactive effects of waterlogging and atmospheric CO2 concentration on gas exchange, growth and functional traits of Australian riparian tree seedlings. *Ecohydrology* **10**, e1803 (2017).
45. Liberloo, M. *et al.* Woody biomass production during the second rotation of a bio-energy Populus plantation increases in a future high CO_2 world. *Global Change Biol.* **12**, 1094-1106 (2006).
46. Lukac, M., Calfapietra, C. & Godbold, D.L. Production, turnover and mycorrhizal colonization of root systems of three *Populus* species grown under elevated CO_2 (POPFACE). *Global Change Biol.* **9**, 838-848 (2003).
47. Matamala, R. & Schlesinger, W.H. Effects of elevated atmospheric CO_2 on fine root production and activity in an intact temperate forest ecosystem. *Global Change Biol.* **6**, 967-979 (2000).
48. Milchunas, D.G., Morgan, J.A., Mosier, A.R. & Lecain, D.R. Root dynamics and demography in shortgrass steppe under elevated CO_2, and comments on minirhizotron methodology. *Global Change Biol.* **11**, 1837-1855 (2005).
49. Norby, R.J., O'Neill, E.G., Hood, W.G. & Luxmoore, R.J. Carbon allocation, root exudation and mycorrhizal colonization of Pinus echinata seedlings grown under CO2 enrichment. *Tree Physiol.* **3**, 302-210 (1987).
50. Norby, R.J. *et al.* Net primary productivity of a CO_2-enriched deciduous forest

and the implications for carbon storage. *Ecol. Appl.* **12**, 1261-1266 (2002).

51. Owensby, C.E., Ham, J.M., Knapp, A.K. & Auen, L.M. Biomass production and species composition change in a tallgrass prairie ecosystem after long-term exposure to elevated atmospheric CO_2. *Global Change Biol.* **5**, 497-506 (1999).
52. Pang, J. *et al.* A new explanation of the N concentration decrease in tissues of rice (*Oryza sativa* L.) exposed to elevated atmospheric *p*CO_2. *Environ. Exper. Bot.* **57**, 98-105 (2006).
53. Pendall, E., Mosier, A.R. & Morgan, J.A. Rhizodeposition stimulated by elevated CO_2 in a semiarid grassland. *New Phytol.* **162**, 447-458 (2004).
54. Pendall, E., Osanai, Y., Williams, A.L. & Hovenden, M.J. Soil carbon storage under simulated climate change is mediated by plant functional type. *Global Change Biol.* **17**, 505-514 (2011).
55. Phillips, D.L., Johnson, M.G., Tingey, D.T., Catricala, C.E., Hoyman, T.L. & Nowak, R.S. Effects of elevated CO_2 on fine root dynamics in a Mojave Desert community: a FACE study. *Global Change Biol.* **12**, 61-73 (2006).
56. Pregitzer, K.S., Burton, A.J., King, J.S. & Zak, D.R. Soil respiration, root biomass, and root turnover following long-term exposure of northern forests to elevated atmospheric CO_2 and tropospheric O_3. *New Phytol.* **180**, 153-161 (2008).
57. Pregitzer, K.S., Zak, D.R., Curtis, P.S., Kubiske, M.E., Teeri, J.A. & Vogel, C.S. Atmospheric CO_2, soil nitrogen and turnover of fine roots. *New Phytol.* **129**, 579-585 (1995).
58. Pregitzer, K.S., Zak, D.R., Maziasz, J., Deforest, J., Curtis, P.S. & Lussenhop, J. Interactive effects of atmospheric CO_2 and soil-N availability on fine roots of *Populus tremuloides*. *Ecol. Appl.* **10**, 18-33 (2000).
59. Prior, S.A., Rogers, H.H., Runion, G.B. & Mauney, J.R. Effects of free-air CO_2 enrichment on cotton root growth. *Agr. Forest Meteorol.* **70**, 69-86 (1994).
60. Pritchard, S.G. *et al*. Root dynamics in an artificially constructed regenerating longleaf pine ecosystem are affected by atmospheric CO_2 enrichment. *Environ. Exper. Bot.* **46**, 55-69 (2001a).

61. Pritchard, S.G. *et al.* The influence of elevated atmospheric CO_2 on fine root dynamics in an intact temperate forest. *Global Change Biol.* **7**, 829-837 (2001b).
62. Pritchard, S.G. *et al.* Fine root dynamics in a loblolly pine forest are influenced by free-air-CO_2-enrichment: a six-year-minirhizotron study. *Global Change Biol.* **14**, 588-602 (2008).
63. Qiao, Y.Z. *et al*. Effects of elevated CO_2 concentration on growth and water use efficiency of winter wheat under two soil water regimes. *Agr. Water Manag.* **97**, 1742-1748 (2010).
64. Radoglou, K.M. & Jarvis, P.G. The effects of CO_2 enrichment and nutrient supply on growth, morphology and anatomy of *Phaseolus vulgaris* seedlings. *Ann. Bot.* **70**, 245-256 (1992).
65. Rey, A. & Jarvis, P.G. Growth response of young birch trees (*Betula pendula* Roth.) after four and a half years of CO_2 exposure. *Ann. Bot.* **80**, 809-816 (1997).
66. Ronn, R., Ekelund, F. & Christensen, S. Effects of elevated atmospheric CO_2 on protozoan abundance in soil planted with wheat and on decomposition of wheat roots. *Plant and Soil* **251**, 13-21 (2003).
67. Runion, G.B. *et al.* Effects of elevated atmospheric carbon dioxide on biomass and carbon accumulation in a model regenerating longleaf pine community. *J. Environ. Qual.* **35**, 1478-1486 (2006).
68. Saha, S., Chakraborty, D., Lata,, P. & Nagarajan, S. Impact of elevated CO_2 on utilization of soil moisture and associated soil biophysical parameters in pigeon pea (*Cajanus cajan* L.). *Agric. Ecosyst. Environ.* **142**, 213-221 (2011).
69. Schappi, B. & Korner, C. Growth responses of an alpine grassland to elevated CO_2. *Oecologia* **105**, 43-52 (1996).
70. Suter, D., Frehner, M., Fischer, B.U., Nosberger, J. & Luscher, A. Elevated CO_2 increases carbon allocation to the roots of *Lolium perenne* under free-air CO_2 enrichment but not in a controlled environment. *New Phytol.* **154**, 65-75 (2002).
71. Thomas, S.M., Whitehead, D., Reid, J.B., Cook, F.J., Adams, J.A. & Leckie, A.C. Growth, loss, and vertical distribution of *Pinus radiata* fine roots growing at

ambient and elevated CO_2 concentration. *Global Change Biol.* **5**, 107-121 (1999).

72. Volder, A., Gifford, R.M. & Evans, J.R. Effects of elevated atmospheric CO_2, cutting frequency, and differential day/night atmospheric warming on root growth and turnover of *Phalaris swards*. *Global Change Biol.* **13**, 1040-1052 (2007).
73. Wan, S.Q., Norby, R.J., Pregitzer, K.S., Ledford, J. & O'neill, E.G. CO_2 enrichment and warming of the atmosphere enhance both productivity and mortality of maple tree fine roots. *New Phytologist* **162**, 437-446 (2004).
74. Wang, Y.P., Rey, A. & Jarvis, P.G. Carbon balance of young birch trees grown in ambient and elevated atmospheric CO_2 concentrations. *Global Change Biol.* **4**, 797-807 (1998).
75. Warwick, K.R., Taylor, G. & Blum, H. Biomass and compositional changes occur in chalk grassland turves exposed to elevated CO_2 for two seasons in FACE. *Global Change Biol.* **4**, 375-385 (1998).
76. Wechsung, G. *et al.* The effects of free-air CO_2 enrichment and soil water availability on spatial and seasonal patterns of wheat root growth. *Global Change Biol.* **5**, 519-529 (1999).
77. Zak, D.R., Pregitzer, K.S., Curtis, P.S., Vogel, C.S., Holmes, W.E. & Lussenhop, J. Atmospheric CO_2, soil-N availability, and allocation of biomass and nitrogen by *Populus tremuloides*. *Ecol. Appl.* **10**, 34-46 (2000).
78. Ziska, L.H., Faulkner, S. & Lydon, J. Changes in biomass and root: shoot ratio of field-grown Canada thistle (*Cirsium arvense*), a noxious, invasive weed, with elevated CO_2: implications for control with glyphosate. *Weed Science* **52**, 584-588 (2004).