Supplementary materials

Spatiotemporal patterns of soil microbial responses to precipitation change

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Figure S1 Global map showing the distribution of studies included in our meta-analysis of microbial responses to drought and irrigation treatments. The circles represent drought treatments and the squares represent irrigation treatments; different colors represent different biomes.

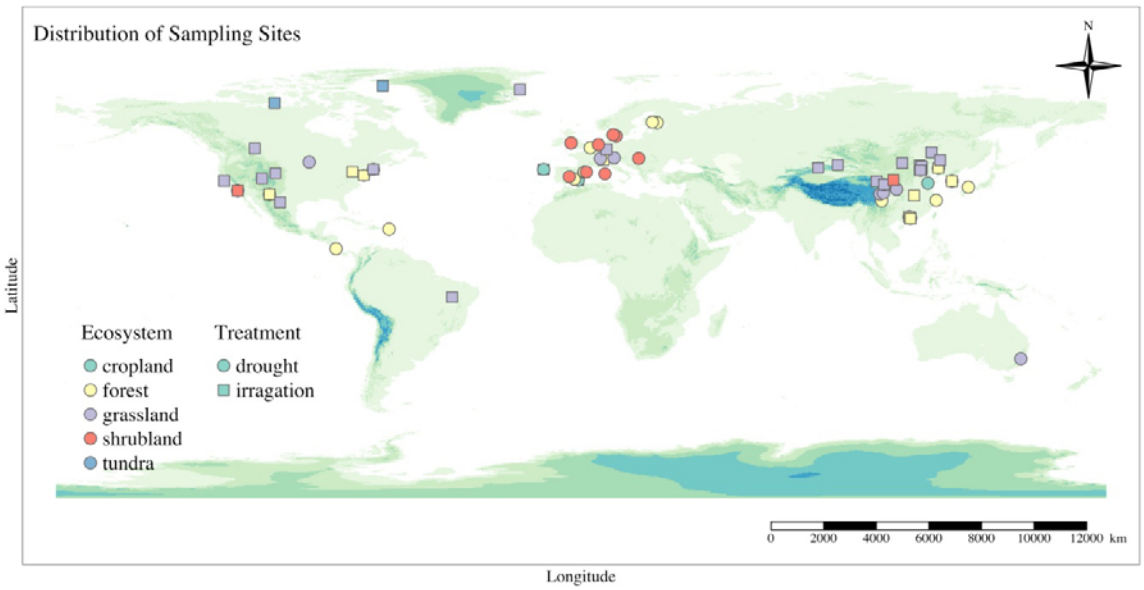

Figure S2 Normal distribution of LnRR of MBC, MBN, MBC to MBN ratio, total PLFAs, fungal PLFAs, bacterial PLFAs, F to B ratio, G+ PLFAs, G- PLFAs and G+ to G- ratio under drought. LnRR: natural log of response ratio; MBC: microbial biomass carbon; MBN: microbial biomass nitrogen; MBC to MBN: microbial biomass carbon to nitrogen ratio; PLFAs is phospholipid fatty acids; F to B ratio is fungi to bacterial PLFA ratio; G+ is Gram-positive bacteria; G- is Gram-negative bacteria; G+ to G- ratio is Gram-positive bacteria to Gram-negative bacteria PLFA ratio.

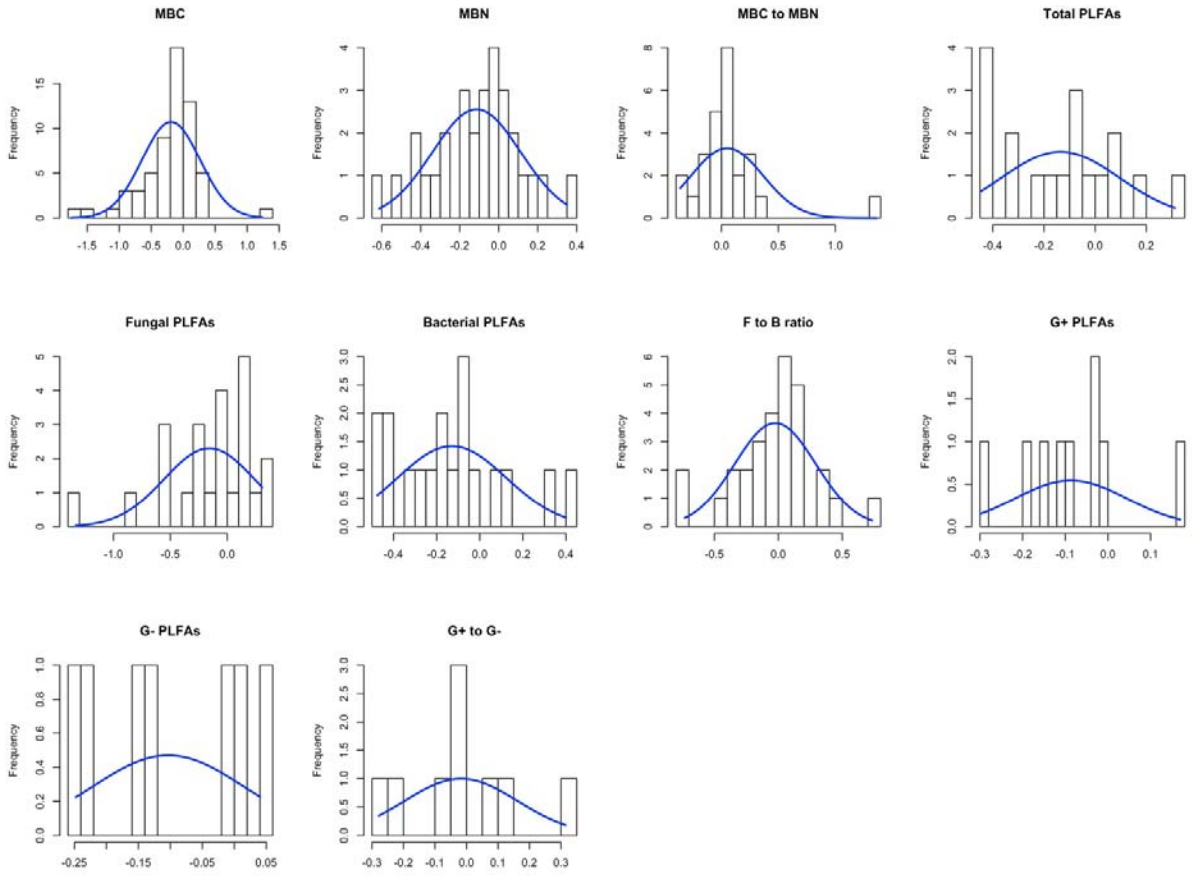

Figure S3 Normal distribution of LnRR of MBC, MBN, MBC to MBN ratio, total PLFAs, fungal PLFAs, bacterial PLFAs, F to B ratio, G+ PLFAs, G- PLFAs and G+ to G- ratio under increased precipitation. LnRR: natural log of response ratio; MBC: microbial biomass carbon; MBN: microbial biomass nitrogen; MBC to MBN: microbial biomass carbon to nitrogen ratio; PLFAs is phospholipid fatty acids; F to B ratio is fungi to bacterial PLFA ratio; G+ is Gram-positive bacteria; G- is Gram-negative bacteria; G+ to G- ratio is Gram-positive bacteria to Gram-negative bacteria PLFA ratio.

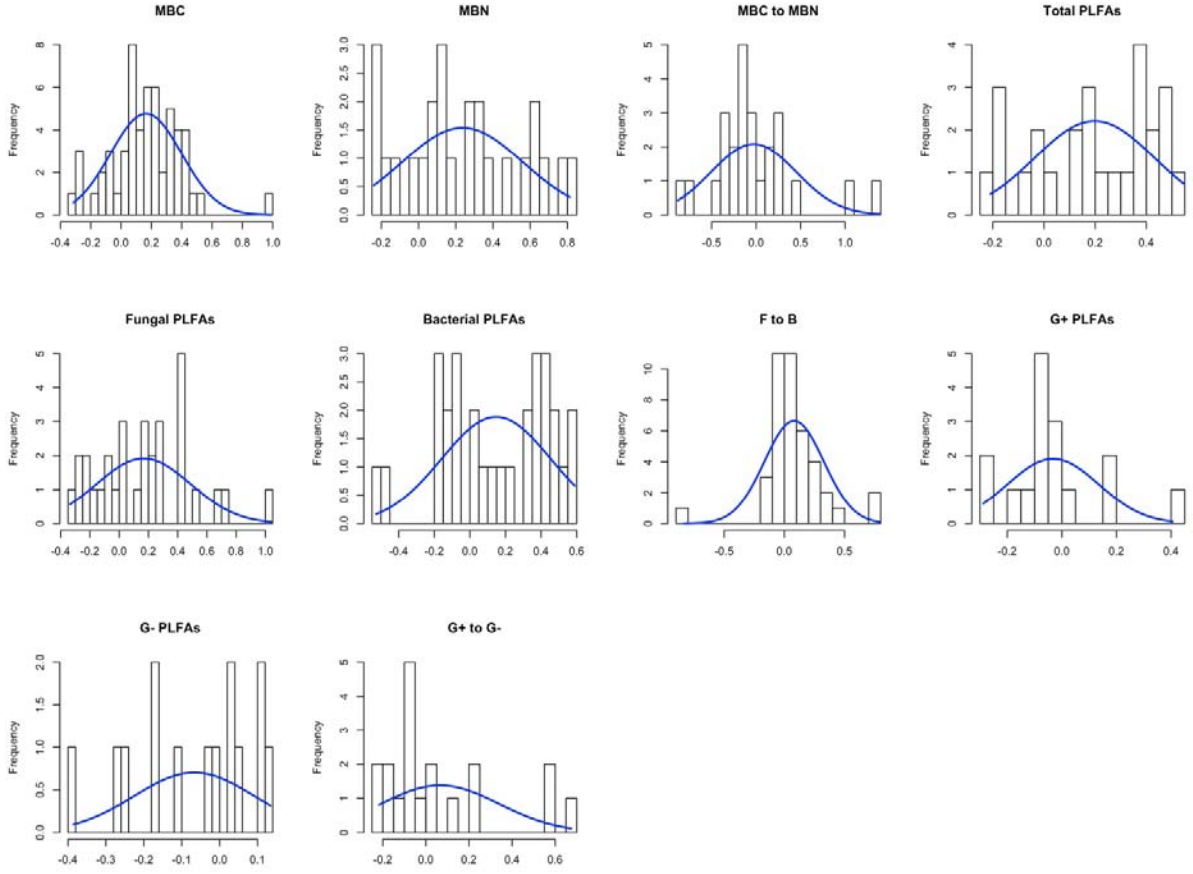

Figure S4 Responses of microbial size and microbial communities in different biomes to altered precipitation, i.e. (a) drought and (b) elevated precipitation; numbers in parentheses represent the number of observations for each parameter for forest (F) grassland (G) and shrubland (S); error bars represent 95% confidence intervals and error bars overlapping the dashed vertical line indicate no effect relative to controls, where MBC is microbial biomass carbon; MBN is microbial biomass nitrogen; PLFAs is phospholipid fatty acids; F: B ratio is fungi to bacterial PLFA ratio; G+ is Gram-positive bacteria; G- is Gram-negative bacteria.

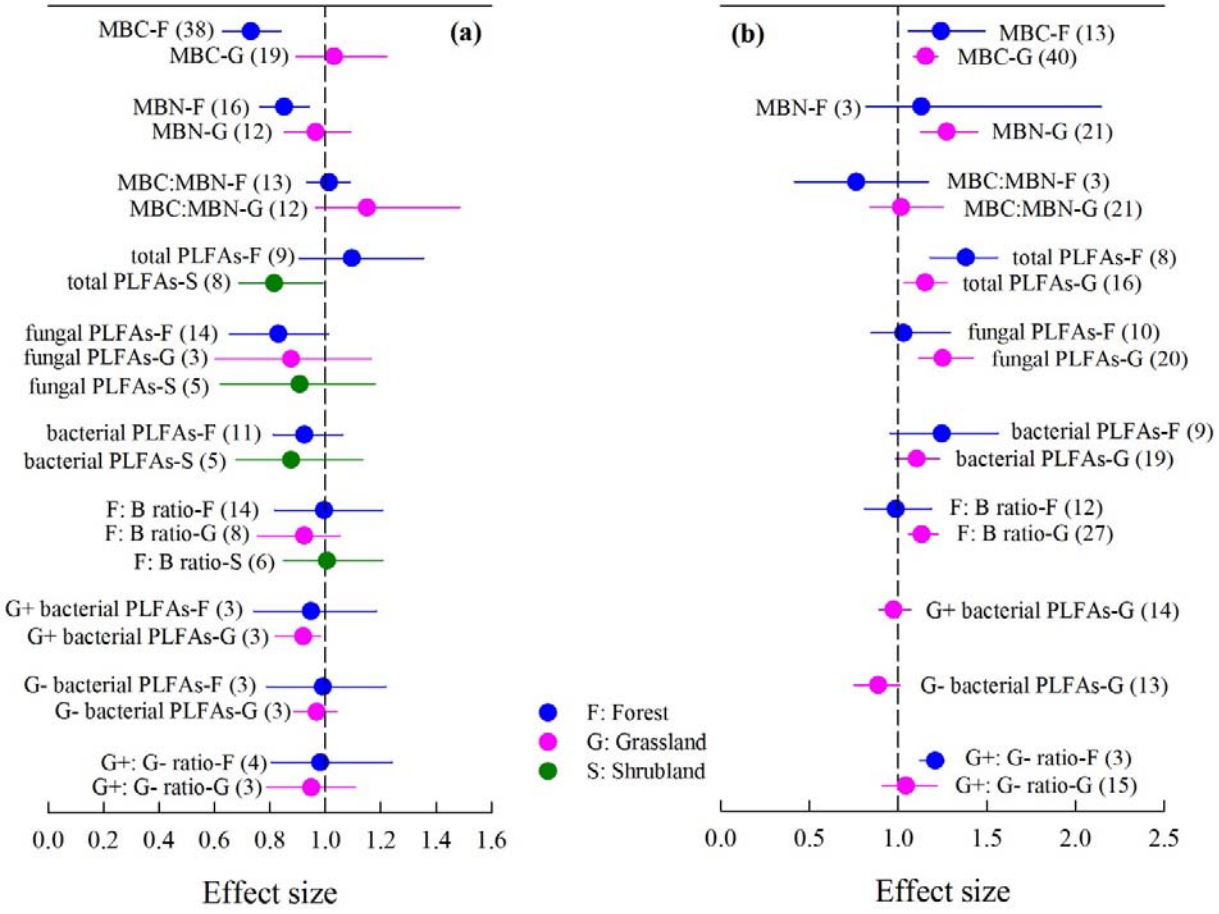

Figure S5 Responses of microbial size and microbial communities in acid soils (pH<7) and alkaline soils (pH>7), to altered precipitation, i.e. (a) drought and (b) elevated precipitation; numbers in parentheses represent the number of observations for each parameter for acid soils and alkaline soils; error bars represent 95% confidence intervals and error bars overlapping the dashed vertical line indicate no effect relative to controls, where MBC is microbial biomass carbon; MBN is microbial biomass nitrogen; PLFAs is phospholipid fatty acids; F: B ratio is fungi to bacterial PLFA ratio; G+ is Gram-positive bacteria; G- is Gram-negative bacteria.

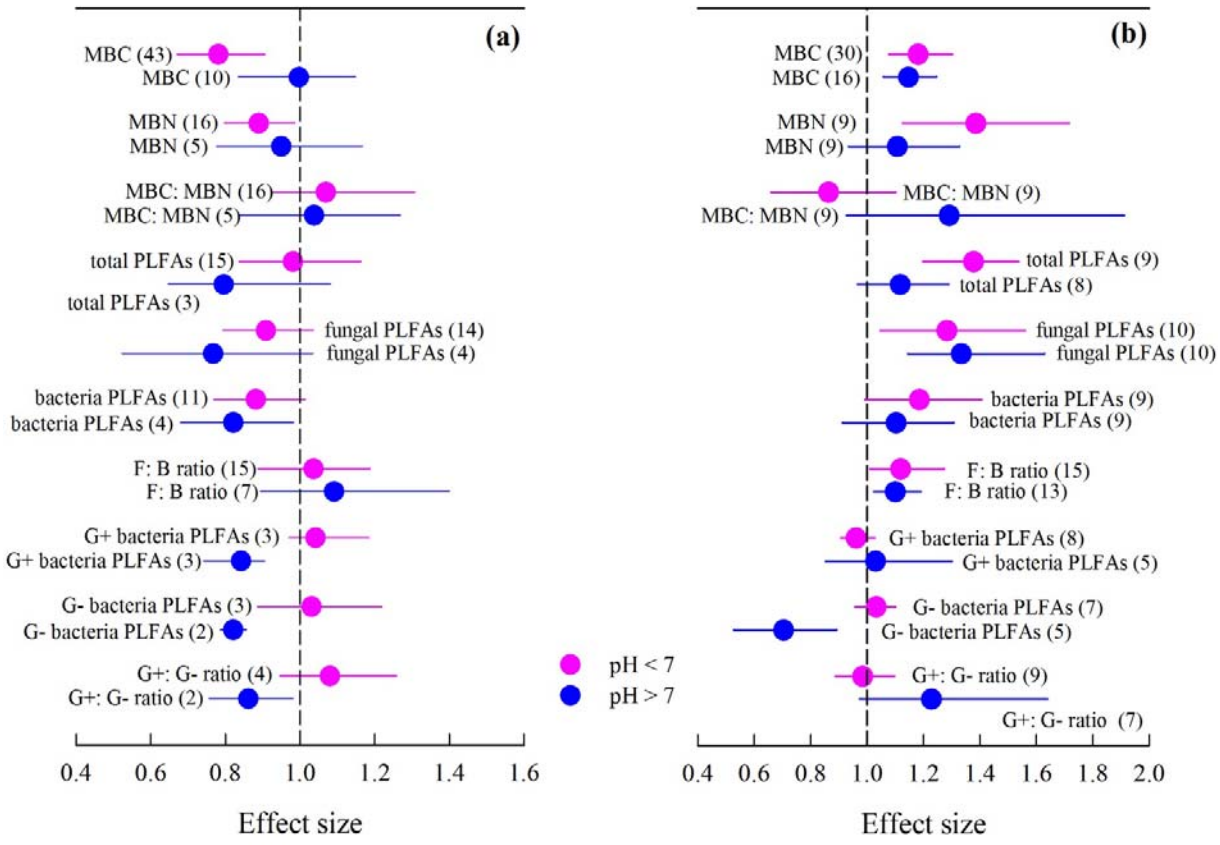

Figure S6 Average aridity index of forest and grassland sites included in our meta-analysis of microbial responses to drought and irrigation treatments, where n is the number of observations and error bars represent the standard error.

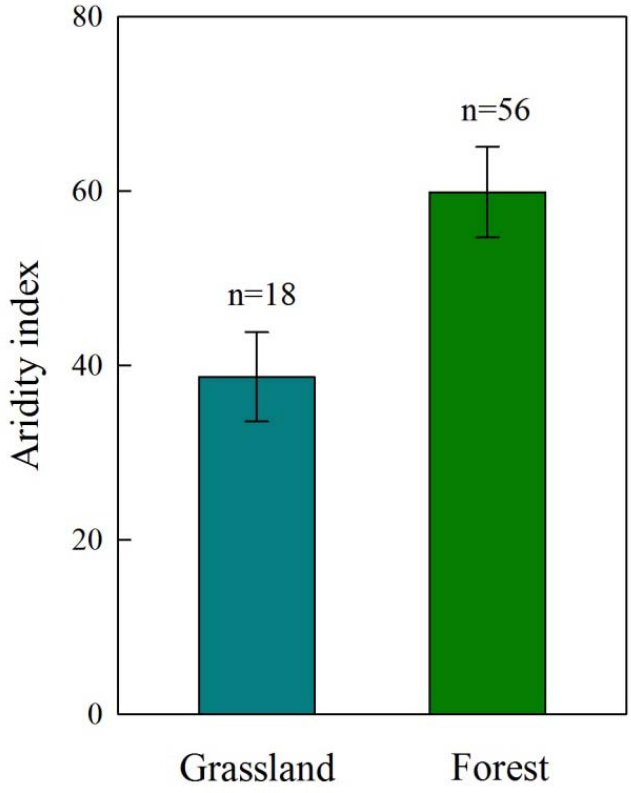

Figure S7 Responses of soil properties to (a) drought and (b) irrigation treatments; numbers in parentheses represent the number of observations for each parameter and error bars represent 95% confidence intervals; error bars overlapping the dashed vertical line indicate no effect relative to controls, where temp. is temperature; SWC is soil water content; SOC is soil organic carbon concentration; DOC is dissolved organic carbon concentration; DON is dissolved organic nitrogen concentration; soil C/N is soil carbon to nitrogen ratio; total soil N is soil nitrogen concentration; soil NH_4^+ is soil ammonium-N concentration; NO_3^- is soil nitrate-N concentration.

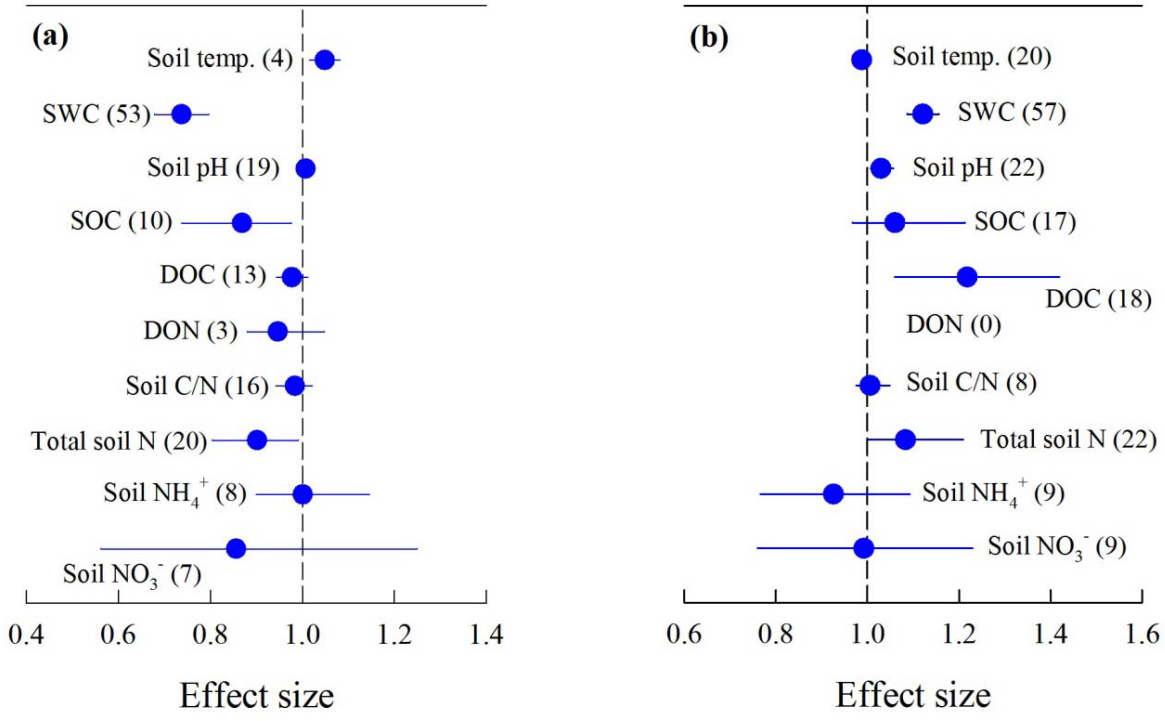

Figure S8 Relationships between the response ratio of soil microbial communities with soil organic carbon content under drought and increased precipitation, where RR is response ratio and MAP is mean annual precipitation. Symbol sizes represent the number of replicates in each study and gray shading represents the confidence interval around the mean (line) when the relationship was significant at $P<0.05$. where MBC is microbial biomass carbon; PLFAs is phospholipid fatty acids; F: B ratio is fungi to bacterial PLFA ratio; SOC is soil organic carbon.

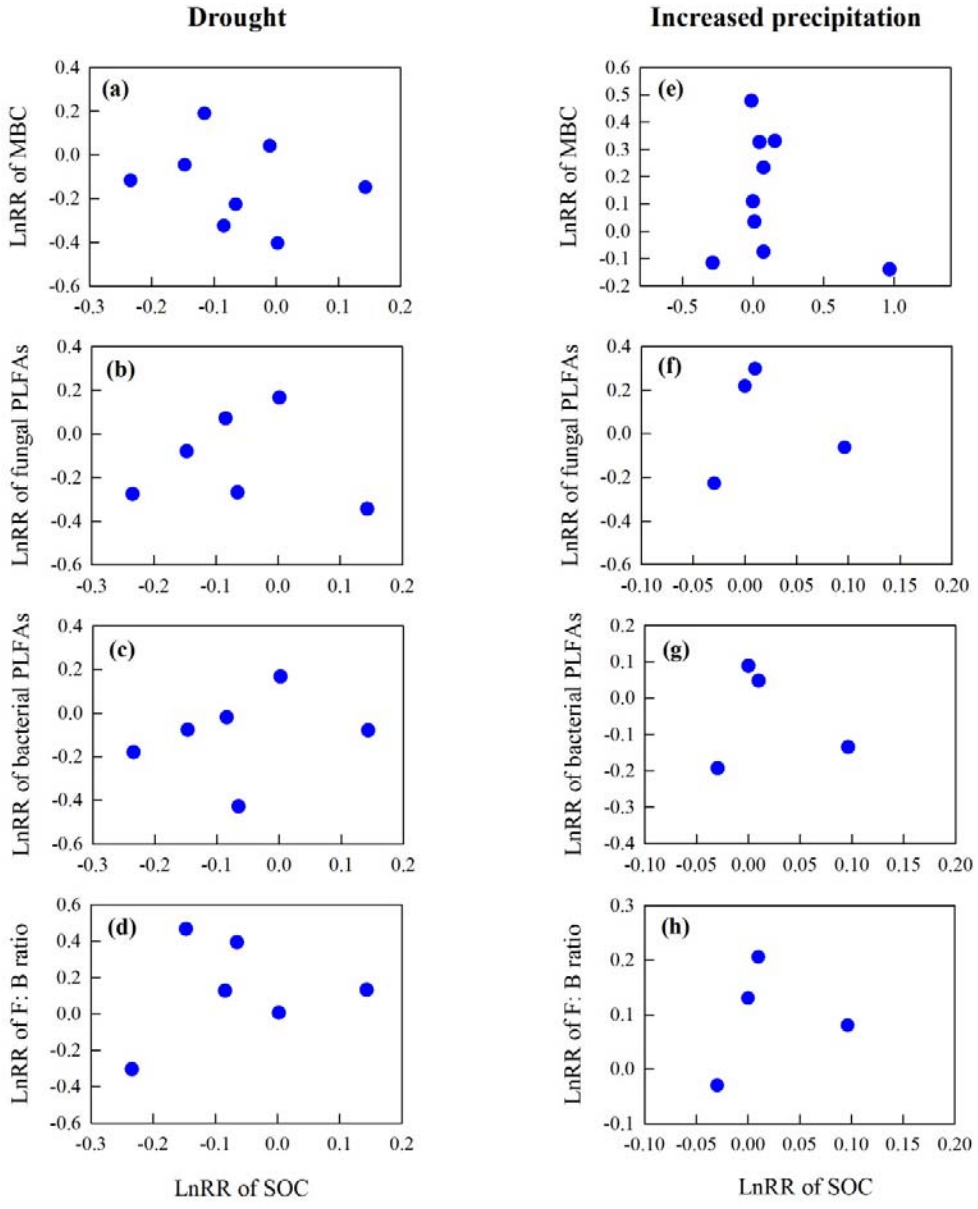

Figure S9 Relationships between the response ratio of soil moisture with treatment level and aridity index under drought and irrigation, where RR is response ratio and MAP is mean annual precipitation. Symbol sizes represent the number of replicates in each study and gray shading represents the confidence interval around the mean (line) when the relationship was significant at $P<0.05$.

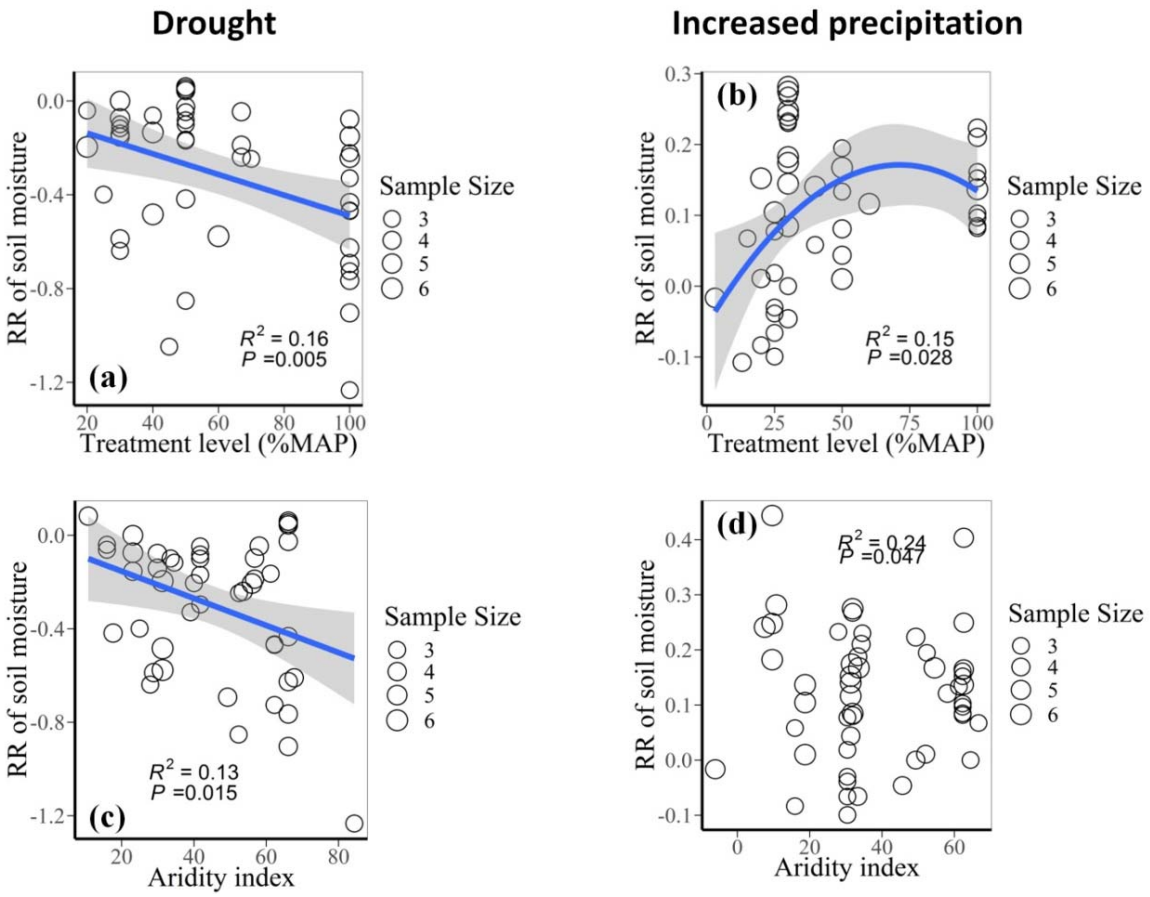

Figure S10 Correlations between the responses of MBC to claysilt (%), MAP (mm) and MAT (℃) under drought and increased precipitation. MBC: microbial biomass carbon; MAP: mean annual precipitation; MAT: mean annual temperature. The correlations were significant when $P<0.05$.

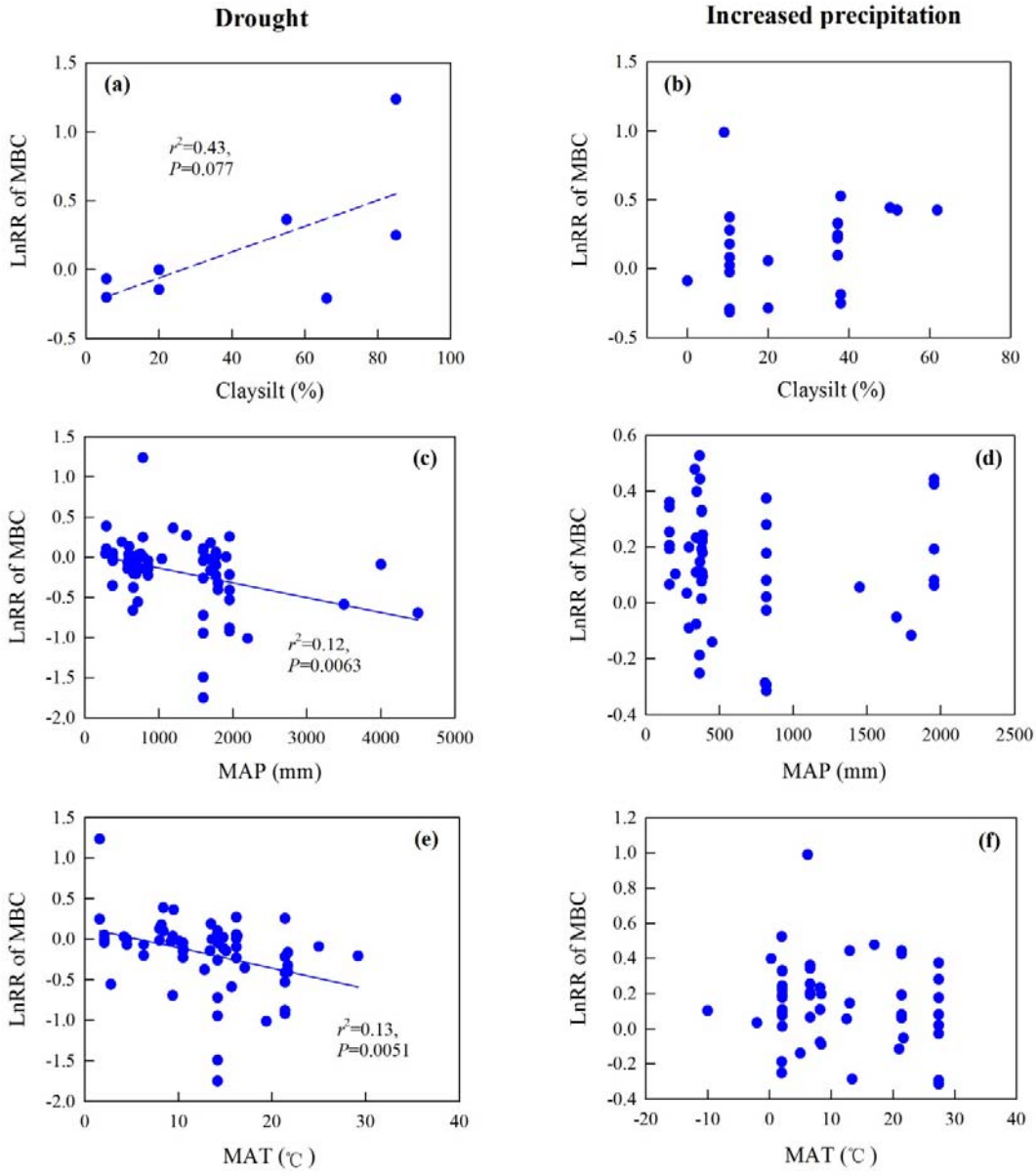

Table S1 The basic information of the drought-treatment studies. No.: number; Lat.: latitude; Long.: Longitude; MAP: mean annual precipitation; MAT: mean annual temperature.

No.	References	Country	Lat. (°)	Long. (°)	MAP (mm)	MAT (℃)	Aridity index	Ecosystem	Treatment level (%)
1	Alster et al. 2013	USA	33.7	-117.7	375.0	17.1	13.8	grassland	251
2	Andresen et al. 2009	Denmark	55.9	12.0	600.0	8.0	33.3	shrubland	--
3	Andresen et al. 2010	Denmark	55.9	12.0	600.0	8.0	33.3	shrubland	--
4	Bastida et al. 2017	Spain	38.4	-2.3	5.3	13.5	0.2	forest	16
5	Bouskill et al. 2013	USA	18.3	-65.8	3500.0	23.0	106.1	forest	100
6	Bu et al. 2018	China	29.9	121.7	1374.7	16.2	52.5	forest	70
7	Canarini et al. 2018	Australia	-33.9	150.7	692.0	29.2	17.7	grassland	50
8	Chen et al. 2017	China	22.7	112.9	1700.0	21.7	53.6	forest	67
9	Cregger et al. 2012	USA	32.3	-106.8	368.0	13.0	16.0	forest	50
10	Cregger et al. 2014	USA	32.3	-106.8	368.0	13.0	16.0	forest	50
11	del Real et al. 2016	USA	45.4	-93.2	660.0	6.3	40.5	grassland	45
12	Domínguez et al. 2017	UK	53.1	-3.5	1700.0	8.2	93.4	shrubland	54
13	Eisenhauer et al. 2012	USA	45.4	-93.2	660.0	6.3	40.5	grassland	45
14	Fan et al. 2017	China	42.9	122.4	452.0	6.2	27.9	forest	30
15	Fang et al. 2012	China	23.2	112.4	1956.0	21.4	62.3	forest	100
16	Fuchslueger et al. 2014	Austrian	47.1	11.3	1097.0	3.0	84.4	grassland	100
17	Hicks et al. 2018	Belgium	--	--	855.0	10.5	41.7	forest	50
18	Hinojosa et al. 2016	Spain	39.4	-4.1	622.0	14.9	25.0	shrubland	25
19	Hueso et al. 2012	Spain	38.0	-1.0	333.0	17.0	12.3	cropland	100
20	Jesen et al. 2003	Denmark	56.4	11.0	758.0	9.4	39.1	shrubland	100
21	Jiang et al. 2013	China	23.2	112.4	1956.0	21.4	62.3	forest	100
22	Khalili et al. 2016	USA	33.7	-117.7	281.0	--	--	grassland	40
23	Krashevska et al. 2012	Ecuador	--	--	2200.0	19.4	74.8	forest	100
24	Landesman and Dighton 2010	USA	40.0	-74.5	1125.0	12.8	49.3	forest	100
25	Li et al. 2018	South Korea	37.6	127.0	792.1	13.6	33.6	forest	30
26	Li et al. 2017	Korea	37.6	127.0	808.9	13.4	34.6	forest	30
27	Lorenz et al. 2001	Germany	--	--	1910.0	4.5	131.7	forest	--
28	Mariotte et al. 2015	Switzerland	46.9	6.6	1393.0	--	--	grassland	20
29	Rousk et al. 2013	European	53.1	-3.5	178.4	--	--	shrubland	30
30	Salamanca et al. 2003	Japan	35.2	132.7	1600.0	14.2	66.1	forest	100
31	Santiago et al. 2016	Spain	-38.3	-1.7	282.0	16.3	10.7	forest	15

32	Sardans and Pen˜uelas 2005	Catalonia	--	--	658.0	12.0	29.9	forest	100
33	Sardans and Pen˜uelas 2010	Catalonia	41.4	1.0	658.0	12.0	29.9	forest	30
34	Sardans et al. 2008	Catalonia	--	--	580.0	15.1	23.1	forest	30
35	Shi et al. 2012	China	32.9	103.6	718.0	2.8	56.1	grassland	--
36	Smolander et al. 2004	Finland	61.2	26.0	580.0	4.5	40.0	forest	--
37	Steinweg et al. 2016	USA	42.4	-12.9	1194.0	9.5	61.2	cropland	50
38	Sun et al. 2017a	China	36.8	118.8	650.0	--	--	cropland	--
39	Sun et al. 2017b	China	--	--	180.0	6.7	10.8	grassland	--
40	Suseela et al. 2014	USA	--	--	1063.0	10.3	52.4	grassland	50
41	van Meeteren et al. 2008	Netherlands	52.4	5.9	1042.0	10.1	51.8	shrubland	50
42	Wang et al. 2013	China	32.4	102.4	786.0	1.6	67.8	grassland	--
43	Wang et al. 2015	China	32.4	102.4	786.0	1.6	67.8	grassland	--
44	Waring and Hawkes 2015	America	10.4	-84.0	4000.0	25.0	114.3	forest	100
45	Xue et al. 2017	China	34.3	108.1	712.0	14.8	28.7	grassland	--
46	Yuste et al. 2011	Spain	41.3	1.8	580.0	15.1	23.1	shrubland	30
47	Zhang et al. 2018	China	36.2	103.8	293.0	8.4	15.9	grassland	40
48	Zhao et al. 2018	China	22.6	112.8	1800.0	21.0	58.1	forest	67
49	Zhao et al. 2016	China	42.0	116.3	379.0	2.1	31.3	grassland	60
50	Zhao et al. 2017	China	22.6	112.8	1800.0	21.7	56.8	forest	67
51	Zhou et al. 2016	China	29.7	103.0	1772.0	16.2	67.6	forest	50

Table S2 The basic information of the increased precipitation-treatment studies. No.: number; Lat.: latitude; Longi.: Longitude; MAP: mean annual precipitation; MAT: mean annual temperature.

No.	References	Country	Lat. (°)	Long. (°)	MAP (mm)	MAT (℃)	Aridity index	Ecosystem	Treatment level (%)
1	Bell and Henry 2011	Canada	43.0	81.2	818.0	7.5	46.7	grassland	23%
2	Bell et al. 2014	USA	29.1	-103.2	365.0	2.0	30.4	grassland	25%
3	Bi et al. 2011	China	42.0	116.3	385.5	2.1	31.9	grassland	30%
4	Chen et al. 2017a	China	42.0	116.3	385.5	2.1	31.9	grassland	50%
5	Chen et al. 2015	China	45.0	110.0	346.1	0.3	33.6	grassland	29%
6	Chen et al. 2017b	China	22.7	112.9	1700.0	21.7	53.6	forest	13%
7	Cregger et al. 2012	New Mexico	32.3	-106.8	368.0	13.0	16.0	forest	18%
8	Cregger et al. 2014	USA	32.3	-106.8	368.0	13.0	16.0	forest	18%
9	Deng et al. 2012	China	112.4	23.2	1956.0	21.4	62.3	forest	100%

10	Deng et al. 2017	China	23.2	112.6	1965.0	21.4	62.6	forest	--
11	Diógenes et al. 2017	Brazil	-9.1	-44.2	818.0	27.4	21.9	grassland	--
12	Evans et al. 2014	USA	40.8	-104.8	341.0	8.2	18.7	grassland	25%
13	Fan et al. 2017	China	42.9	122.4	452.0	6.2	27.9	forest	30%
14	Fang et al. 2012	China	23.2	112.4	1956.0	21.4	62.3	forest	100%
15	Guenet et al. 2012	Germany	50.5	8.7	580.0	9.4	29.9	grassland	--
16	Gutknecht et al. 2012	USA	37.7	-122.4	787.0	3.6	57.9	grassland	50%
17	Hartmann et al. 2017	Switzerland	46.3	7.6	657.0	9.2	34.2	forest	100%
18	Henry et al. 2005	USA	37.7	-122.4	582.0	15.5	22.8	grassland	50%
19	Hewins et al. 2016	Canada	50.9	-111.9	354.0	4.2	24.9	grassland	20%
20	Huang et al. 2015a	China	44.3	87.9	160.0	6.6	9.6	grassland	30%
21	Huang et al. 2015b	China	44.3	87.9	160.0	6.6	9.6	grassland	15%
22	Huang et al. 2018	China	44.3	87.9	160.0	6.6	9.6	grassland	30%
23	Hueso et al. 2011	Spain	38.0	-1.0	333.0	17.0	12.3	cropland	--
24	Illeris et al. 2003	Denmark	74.5	-21.0	200.0	‐ 10	--	grassland	--
25	Jiang et al. 2013	China	112.4	23.2	1956.0	21.4	62.3	forest	100%
26	Khalili et al. 2016	USA	33.7	-117.7	281.0	--	28.1	grassland	40%
27	Landesman and Dighton 2010	USA	40.0	-74.5	1125.0	12.8	49.3	forest	100%
28	Li et al. 2018	South Korea	37.6	127.0	1450.5	12.5	64.5	forest	30%
29	Li et al. 2016	China	42.0	116.3	379.4	2.1	31.4	grassland	50%
30	Li et al. 2017	Korea	37.6	127.0	808.9	13.4	34.6	forest	30%
31	Liu et al. 2009	China	42.0	116.3	385.5	2.1	31.9	grassland	30%
32	Ma et al. 2013	China	49.3	120.0	350.0	∼-3 and -1	--	grassland	30%
33	Ma et al. 2015	China	49.3	120.0	278.2	‐ 3∼ ‐ 1	--	grassland	--
34	Ma et al. 2016	China	44.0	116.0	343.0	0.3	33.3	grassland	--
35	McDaniel et al. 2013	Pennsylvania	41.4	-78.4	968.0	8.6	52.0	forest	20%
36	Raiesi 2004	Iran	--	--	450.0	5.0	30.0	cropland	--
37	Schaeffer et al. 2013	Denmark	76.0	-68.0	--	--	--	tundra	--
38	Seo et al. 2015	Canada	69.1	-105.1	140.0	−33	-6.1	tundra	3%
39	Shao et al. 2018	China	42.0	116.3	382.3	2.1	31.6	grassland	30%
40	She et al. 2018	China	38.0	107.0	284.8	8.1	15.7	shrubland	20%
41	Shi et al. 2018	China	31.8	114.1	1150.0	15.2	45.6	forest	30%
42	Song et al. 2012	China	42.0	116.3	382.3	2.1	31.6	grassland	31%
43	Steinweg et al. 2016	USA	42.4	-12.9	1194.0	9.5	61.2	cropland	50%
44	Su et al. 2016	China	44.3	87.9	133.7	7.7	7.6	grassland	30%
45	Sun et al. 2017a	China	42.0	116.3	180.0	6.7	10.8	grassland	30%

46	Sun et al. 2015	China	44.0	116.0	400.0	-0.4	66.7	grassland	15%
47	Sun et al. 2017b	China	46.2	123.0	400.0	4.6	27.4	grassland	15%
48	Suseela et al. 2014	America	42.4	-71.2	1063.0	10.3	52.4	grassland	50%
49	Wang et al. 2014	China	42.0	116.3	379.4	2.1	31.4	grassland	50%
50	Xiao et al. 2007	China	42.0	116.3	387.0	2.1	32.0	grassland	50%
51	Yan et al. 2010	China	42.5	116.7	385.0	2.1	31.8	grassland	30%
52	Yang et al. 2017	China	42.0	116.3	379.4	2.1	31.4	grassland	50%
53	Zelikova et al. 2012	USA	38.7	-109.4	183.0	13.1	7.9	grassland	--
54	Zhang et al. 2016a	China	43.6	116.7	346.0	0.3	33.6	grassland	50%
55	Zhang et al. 2016b	China	37.5	101.2	485.0	-1.1	54.5	grassland	50%
56	Zhang et al. 2013	China	42.0	116.0	385.5	2.1	31.9	grassland	30%
57	Zhang et al. 2018	China	36.2	103.8	293.0	8.4	15.9	grassland	20%
58	Zhao et al. 2017	China	22.6	112.8	1800.0	21.7	56.8	forest	--
59	Zhao et al. 2018	China	22.6	112.8	1800.0	21.0	58.1	forest	--
60	Zhao et al. 2016	China	42.0	116.3	379.0	2.1	31.3	grassland	20%
61	Zhou et al. 2013a	China	42.0	116.3	383.0	2.1	31.7	grassland	30%
62	Zhou et al. 2013b	China	42.0	116.3	383.0	2.1	31.7	grassland	30%

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