

Appendix S1

Chronic fertilization and irrigation gradually and increasingly restructure grassland communities. Kaitlin Kimmel, Laura Dee, Dave Tilman, Isabelle Aubin, Gerhard Boenisch, Jane A. Catford, Jens Kattge, Forest Isbell. *Ecosphere*.

Table S1: Comparison of results using high N treatments (+14 g N/m²/year) only, grouped N treatments (+7 or +14 g N/m²/year), and both N treatments for species richness and functional dispersion as examples. The “*Fert*” row refers to either grouped treatments or the high N addition treatment depending on column heading. All other rows are as in Table 1 of main text. Values are effect size (standard error). *- p < 0.05, ** - p < 0.01, *** - p < 0.001

	Species Richness			Functional Dispersion		
	High N	Grouped N	Both N	High N	Grouped N	Both N
<i>Intercept</i>	22.42 (24.74) ***	20.62 (3.73) ***	20.62 (3.69) ***	0.13 (0.04) ***	0.13 (0.03)***	0.13 (0.03) ***
<i>SPEI</i>	6.78 (2.26) ***	5.69 (1.78) ***	5.69 (1.76) ***	-0.04 (0.02) ***	-0.04 (0.02)***	-0.04 (0.02) ***
<i>Biomass</i>	0.01 (0.005) ***	0.01 (0.004) ***	0.01 (0.004) ***	0.00001 (0.00004)	0.000006 (0.00004)	0.000006 (0.00004)
<i>Year</i>	-5.07 [†] (2.28)***	-3.99 [†] (1.79)***	-3.99 [†] (1.79) ***	0.03 [†] (0.02)	0.03 [†] (0.02)**	0.03 [†] (0.02)**
<i>Fert (+7 only)</i>	---	---	-0.14 (1.39)	---	---	0.01 (0.01)
<i>Fert</i>	1.97 (1.43)	0.92(1.21)	1.97 (1.39)	-0.003 (0.001)	0.004 (0.01)	-0.003 (0.01)
<i>Irr</i>	0.94 (1.43)	0.85 (1.31)	0.85 (1.31)	0.003 (0.001)	0.007 (0.01)	0.007 (0.01)
<i>Fert(+7 only):Irr</i>	---	---	1.23 (1.61)	---	---	-0.03 (0.01) ***
<i>Fert:Irr</i>	0.40 (1.63)	0.82 (1.39)	0.40 (1.61)	-0.004 (0.01)	-0.02 (0.01) ***	-0.004 (0.01)
<i>Fert(+7 only):Year</i>	---	---	-1.74 (0.57) ***	---	---	-0.001 (0.01)
<i>Fert:Year</i>	-3.13 (0.61) ***	-2.43 (0.50) ***	-3.13 (0.57) ***	-0.003 (0.01)	-0.002 (0.01)	-0.003 (0.01)
<i>Irr:Year</i>	-1.34 (0.61) ***	-1.28 (0.47) ***	-1.28 (0.47) ***	0.003 (0.01)	0.0003 (0.004)	0.0003 (0.004)

Table S2: Datasets from TRY (request IDs: 4261 & 4354) and associated references. Note that the five datasets with the most observations are from the Midwest region or from Cedar Creek which accounts for over 50% of the trait data used from TRY.

Dataset	Reference	Observations
Midwestern and Southern US Herbaceous Species Trait Database	unpub.	1610
Plant traits of grassland species	(La Pierre and Smith 2015)	1538
Plant traits from Wisconsin, USA	unpub.	1050
Cedar Creek prairie plants (leaf, seed, dispersule, height, plant, root)	(Catford et al. n.d.)	671
Cedar Creek Savanna SLA, C, N Database	(Willis et al. 2010)	624
New York Old Field Plant Traits Database	(Siefert 2012)	584
The LEDA Traitbase	(Kleyer et al. 2008)	472
Plant Traits for Pinus and Juniperus Forests in Arizona	(Laughlin et al. 2010)	284
California Coastal Grassland Database	(Sandel et al. 2011)	216
The VISTA Plant Trait Database	(Garnier et al. 2007)	216
Plant Traits from LTER Matsch (Mazia), Italy	unpub.	200
FRED - Fine Root Ecology Database	(Iversen et al. 2017)	183
Eastern US Old Field Plant Traits Database	(Siefert et al. 2014)	170
Old fields of Eastern US (Siefert Data)	(Siefert et al. 2014)	170
GLOPNET - Global Plant Trait Network Database	(Wright et al. 2004)	162
Categorical Plant Traits Database	unpub.	155
Global Respiration Database	(Reich et al. 2008)	138
Rocky Mountain Biological Laboratory WSR/gradient plant traits	unpub.	119
Aboveground morphological traits of grassland species	(Abakumova et al. 2016)	110
Leaf and Whole Plant Traits Database	unpub.	97
French Alps Trait Data	(Gos et al. 2016)	89
Photosynthesis Traits Worldwide	(Maire et al. 2015)	79
Leaf Economic Traits Across Varying Environmental Conditions	(Wright and Sutton-Grier 2012)	78
French Massif Central Grassland Trait Database	(Louault et al. 2005)	72
Ecological Flora of the British Isles	(Fritter and Peat 1994)	71
Leaf and Whole Plant Traits Database	(Shipley 2002)	70
Flora Italia Functional Traits Hoard (FIFTH)	(Cerabolini et al. 2010)	69
Traits of 59 grassland species	(Schroeder-Georgi et al. 2016)	55
Grassland Plant Trait Database	(Takkis n.d.)	54
Reich-Oleksyn Global Leaf N, P Database	(Reich et al. 2009)	52
Italian Alps Plant Traits Database	(Bragazza 2009)	51
Leaf Physiology Database	(Kattge et al. 2009)	49
Global Respiration Database	(Atkin et al. 2015)	46
Leaf Allometry Dataset	(Price and Enquist 2007)	40
PLANTSdata USDA	(Green 2009)	33
Chinese Traits	(Prentice et al. 2011)	24
Plant Physiology Database	(Campbell et al. 2007)	24
Leaf Area, Dry Mass and SLA Dataset	unpub.	24
Northern mixed-grass prairie species traits - Wyoming, USA	unpub.	20
Traits of the Hungarian flora	(Lhotsky et al. 2016)	20
Plant Traits from Fynbos Forests in the Cape Region	(Onstein et al. 2014)	19
The DIRECT Plant Trait Database	(Fry et al. 2014)	19
BASECO: a floristic and ecological database of Mediterranean French flora	(Gachet et al. 2005)	18

The Netherlands Plant Height Database	unpub.	18
Leaf Structure, Venation and Economic Spectrum	(Blonder et al. 2012)	18
Photosynthesis and Leaf Characteristics Database	unpub.	18
Saskatchewan Plant Trait Database	(Guy et al. 2013)	18
Abisko & Sheffield Database	(Quested et al. 2003)	16
The Netherlands Plant Traits Database	(Ordoñez et al. 2010)	15
The Xylem/Phloem Database	(Schweingruber and Landolt 2005)	15
Sheffield Database	(Cornelissen et al. 1999)	14
Hokkaido leaf traits	(Mori et al. 2015)	13
PLANTATT - Attributes of British and Irish Plants	(Hill et al. 2004)	13
Sheffield-Iran-Spain Database	(Díaz et al. 2004)	13
The DIRECT Plant Trait Database	(Everwand et al. 2014)	11
Traits related to riparian plant invasion in South East Australia	(Catford et al. 2014)	11
Maxfield Meadow, Rocky Mountain Biological Laboratory - LMA	unpub.	10
Plant Physiology Database	(Loveys et al. 2003)	9
Plant Traits from Romania	(Ciocârlan 2000)	9
Abisko & Sheffield Database	(Cornelissen et al. 2004)	8
Leaf and Whole Plant Traits Database	(Meziane and Shipley 1999)	8
Nutrient Resorption Efficiency Database	(Vergutz et al. 2012)	8
Overton/Wright New Zealand Database	unpub.	8
TOPIC (Traits of Plants in Canada)	(Aubin et al. 2016)	7
Chinese Leaf Traits Database	(Han et al. 2004)	6
Functional Traits of Graminoids in Semi-Arid Steppes Database	(Adler et al. 2004)	6
Herbaceous Traits from the ÷land Island Database	(Hickler 1999)	6
Leaf N-Retention Database	(de Vries and Bardgett 2016)	6
The Americas N&P database	(Kerkhoff et al. 2006)	5
A Global Data Set of Leaf Photosynthetic Rates, Leaf N and P, and Specific Leaf Area	(Walker 2014)	4
Fonseca/Wright New South Wales Database	(Fonseca et al. 2000)	4
Leaf Traits and Seed Mass of Cover Crops	(Tribouillois et al. 2015)	4
Dispersal Traits Database	unpub.	3
Plant Coastal Dune Traits (France, Aquitaine)	unpub.	3
Functional traits explaining variation in plant life history strategies	(Adler et al. 2014)	2
Leaf and Whole Plant Traits Database	(Shipley and Lechowicz 2000)	2
Leaf Ash Content in China's Terrestrial Plants	(Han et al. 2012)	2
Leaf Traits Mount Hutt, New Zealand	(Kichenin et al. 2013)	2
Plant Physiology Database	(Atkin et al. 1997)	2
Plant Trait Database in East and South-East Asia	(Koike 2001)	2
Plant Traits of Acidic Grasslands in Central Spain	(Peco et al. 2005)	2
The Functional Ecology of Trees (FET) Database - Jena	(Wirth and Lichstein 2009)	2
Leaf and Whole Plant Traits Database	(Shipley 1995)	1
Leaf and Whole Plant Traits Database	(Shipley and Vu 2002)	1
Leaf and Whole Plant Traits Database	(Vile 2005)	1
Photosynthesis Traits Database	unpub.	1
Herbaceous Plants Traits From Southern Germany	unpub.	1
Mediterranean psammophytes	(Ciccarelli 2015)	1

Table S3: Percent trait coverage for height, leaf N content, and SLA. There was >89% coverage for all treatments each year. All species had a photosynthetic pathway, so coverage was 100% for all years and treatments.

Year	N Treatment	Water Treatment	Species Coverage			Biomass Coverage		
			Height	Leaf N	SLA	Height	Leaf N	SLA
2007	ambient	ambient	100	100	100	100	100	100
	Fertilized	ambient	99.24	99.17	100	99.94	99.99	100
	ambient	Irrigated	99.24	99.24	99.24	99.99	99.99	99.99
2009	Fertilized	Irrigated	100	98.26	100	100	99.93	100
	ambient	ambient	98.55	97.57	99.28	99.64	99.97	99.99
	Fertilized	ambient	97.63	95.20	97.63	99.93	98.89	99.93
2010	ambient	Irrigated	100	100	100	100	100	100
	Fertilized	Irrigated	97.88	97.96	99.07	99.95	99.99	99.86
	ambient	ambient	96.64	87.30	96.64	99.933	99.63	99.99
2015	Fertilized	ambient	98.72	90.55	98.72	98.96	99.45	99.96
	ambient	Irrigated	100	97.36	100	100	99.51	100
	Fertilized	Irrigated	98.41	89.44	98.41	99.91	98.71	99.91
2016	ambient	ambient	97.86	89.44	97.86	99.97	89.11	99.97
	Fertilized	ambient	96.01	84.91	98.03	96.52	95.19	99.97
	ambient	Irrigated	97.54	89.06	97.54	99.95	92.73	99.99
2016	Fertilized	Irrigated	96.75	89.66	98.72	99.82	99.03	99.99
	ambient	ambient	96.96	94.52	96.96	99.85	99.25	99.85
	Fertilized	ambient	94.29	90.70	94.29	98.62	97.92	98.62
2016	ambient	Irrigated	99.12	98.43	99.12	99.99	99.96	99.99
	Fertilized	Irrigated	98.81	94.81	98.81	99.99	99.45	99.99

Table S4: Functional group biomass responds to both irrigation and fertilization treatments through time. Columns correspond with the individual functional groups. Models were run using the proportion of biomass characterized by the specified functional groups. Rows correspond to model parameters, --- means that those parameters were not included in the model. Values are effect size (standard error) *- p < 0.05, ** - p < 0.01, *** - p < 0.001

	C4 Grass	C3 Grass	Legume	Non-legume Forb
<i>Intercept</i>	0.81 (0.11) ***	-0.09 (0.20)	0.74 (0.09)***	0.32 (.025)
<i>SPEI</i>	0.11 (0.07)	-0.16 (0.09) **	-0.122 (0.06)***	0.28 (0.18) ***
<i>Biomass</i>	0.004 (0.004)	-0.0003 (0.0002)	-0.001 (0.0004) ***	0.001 (0.0003) ***
<i>Year</i>	-0.06 (0.02) **	0.23 [†] (0.10) ***	0.04 (0.02) **	-0.11 [†] (0.12)
<i>Fert</i>	0.05 (0.06)	0.12 (0.06) ***	-0.16 (0.06) ***	0.14 (0.08) *
<i>Irr</i>	0.12 (0.06) **	0.16 (0.06) ***	-0.16 (0.04) **	0.09 (0.08)
<i>Fert:Irr</i>	-0.07 (0.07)	-0.11 (0.06) *	0.10 (0.07)	-0.15 (0.11)
<i>Fert:Year</i>	0.02 (0.01)***	0.03 (0.03)	-0.005 (0.006)	-0.18 (0.04) ***
<i>Irr:Year</i>	0.01 (0.01)	-0.06 (0.03) ***	0.02 (0.006) ***	-0.13 (0.04)***
<i>Fert:Irr:Year</i>	---	---	---	0.12 (0.06) **

Table S5: Fertilization either immediately impacts community weighted trait values or has a continuous effect whereas irrigation only has immediate and persistent effects. Output for the fixed effects of individual traits (columns), abundance weighted and not. Rows correspond to model parameters, --- means that those parameters were not included in the model. Values are effect size (standard error) *- p < 0.05, **- p < 0.01, *** - p < 0.001

	Abundance weighted				Non-Abundance weighted			
	SLA	Leaf N	Height	C3	SLA	Leaf N	Height	C3
<i>Intercept</i>	16.04 (0.44) ***	16.32 (1.06) ***	0.51 (0.09) ***	0.77 (0.11) ***	16.06 (0.33) ***	14.74 (1.49) ***	0.32 (0.05) ***	0.43 (0.10) ***
<i>SPEI</i>	---	-1.48 (0.74) **	0.10 (0.04) ***	-0.11 (0.07)	---	-1.92 (1.26)	0.13 (0.04) ***	-0.26 (0.07) ***
<i>Biomass</i>	---	-0.005 (0.004)	0.002 (0.0001) ***	-0.0004 (0.0004)	---	0.004 (0.004)	0.0006 (0.0001) ***	0.0002 (0.0004)
<i>Year</i>	-0.12 (0.04) ***	0.33 (0.24)	-0.05 [†] (0.04)	0.06 (0.02) ***	-0.12 (0.04) ***	6.61 (13.45)	-1.14 (0.45)***	0.08 (0.02) ***
<i>Year²</i>	---	---	---	---	---	-1.07 (4.36)	0.30 (0.11) ***	---
<i>Fert</i>	1.07 (0.60) *	-0.71 (0.60)	0.06 (0.03) *	-0.06 (0.06)	1.26 (0.44) ***	-0.50 (0.42)	-0.03 (0.02)	0.06 (0.06)
<i>Irr</i>	0.92 (0.51) *	-1.80 (0.60) ***	0.04 (0.03)	-0.12 (0.06) **	0.78 (0.44) *	-1.14 (0.42) ***	0.01 (0.02)	-0.04 (0.06)
<i>Fert:Irr</i>	-0.89 (0.65)	0.31 (0.71)	-0.10 (0.04) ***	0.07 (0.07)	-0.92 (0.55)	-0.04 (0.59)	0.02 (0.02)	-0.08 (0.09)
<i>Fert:Year</i>	0.07 (0.05)	-0.02 (0.07)	-0.05 (0.02) **	-0.02 (0.007) ***	0.05 (0.05)	-2.32 (2.70)	-0.13 (0.09)	-0.04 (0.01) ***
<i>Irr:Year</i>	-0.07 (0.05)	0.07 (0.07)	-0.02 (0.02)	-0.009 (0.007)	-0.05 (0.05)	0.26 (2.70)	-0.01 (0.09)	-0.02 (0.01) ***
<i>Fert: Year²</i>	---	---	---	---	---	0.91(2.70)	0.04 (0.09)	---
<i>Irr: Year²</i>	---	---	---	---	---	8.32 (2.70) ***	-0.22 (0.09) ***	---
<i>Fert:Irr:Year</i>	---	---	0.07 (0.02) ***	---	---	---	---	0.03 (0.01) ***

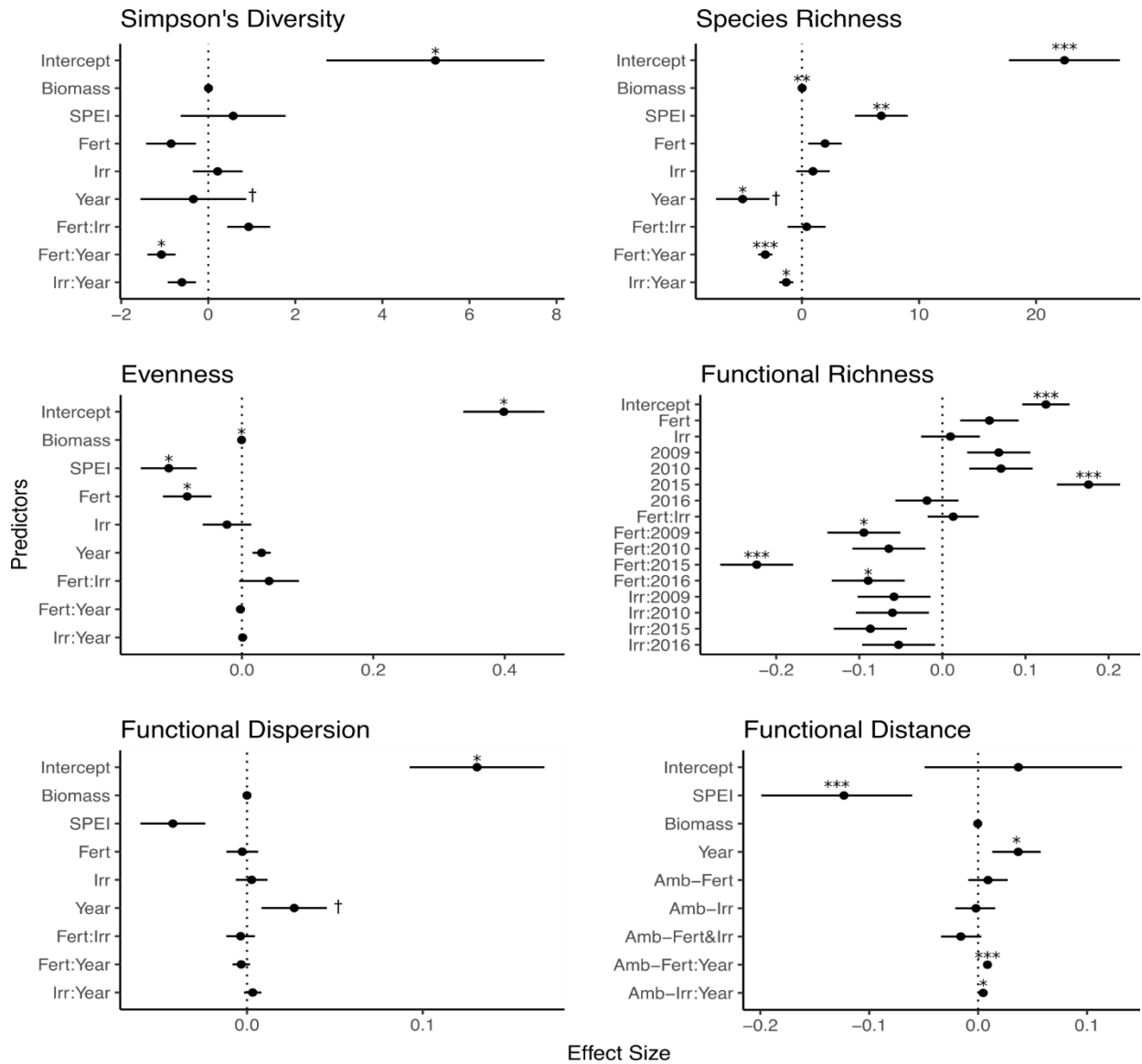


Figure S1: Fertilization continually impacts five of the six community metrics, whereas irrigation only significantly impacts two of six. Output from mixed effects models showing the impact of the fertilization and irrigation treatments on community metrics (panels) through time. The y-axis correspond to model parameters: SPEI is the standardized precipitation evapotranspiration index, Biomass is the average biomass across all plots for that year, Year corresponds to duration of experiment (0 = 2007, 9 = 2016), † in the year row indicates that the model was fit to the log of year, Fert is the nitrogen addition treatments and Irr is the irrigation treatments. The x-axis is the effect size and error bars are standard errors, or in the case of functional distance, 95% confidence intervals. *- p < 0.05, ** - p < 0.01, *** - p < 0.001

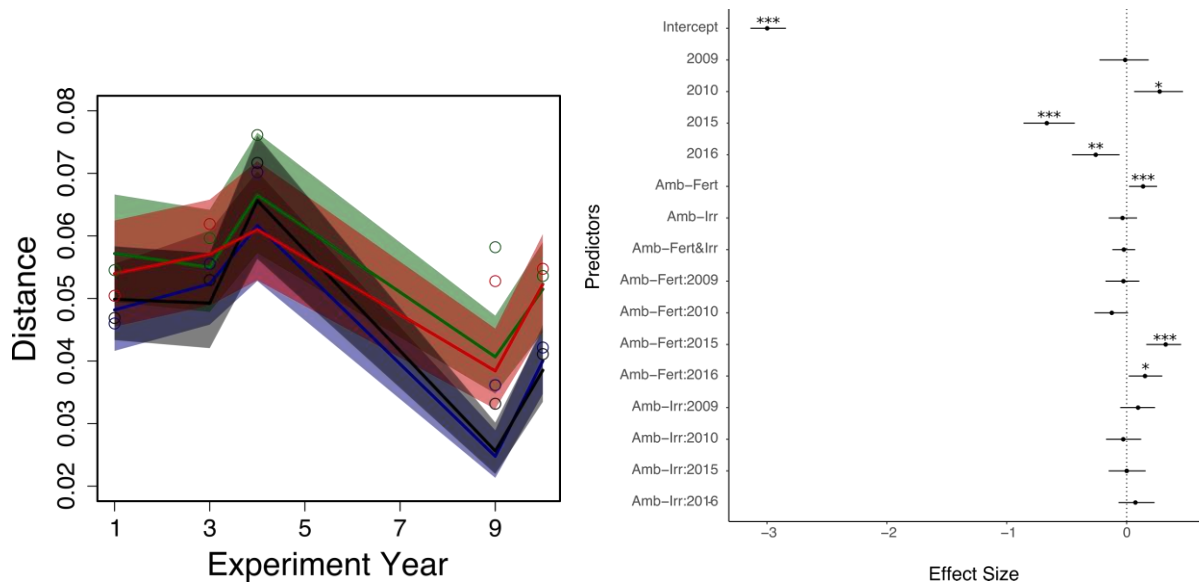


Figure S2: Fertilization causes plots to become increasingly dissimilar when considering non-weighted trait values, a temporally varying effect (left). Points are means, lines are estimated from the MCMCglmm output, and error bands are the upper and lower 95% confidence intervals. The right panel shows the effect sizes and the 95% confidence interval for each parameter in the MCMCglmm model. *- $p < 0.05$, ** - $p < 0.01$, *** - $p < 0.001$

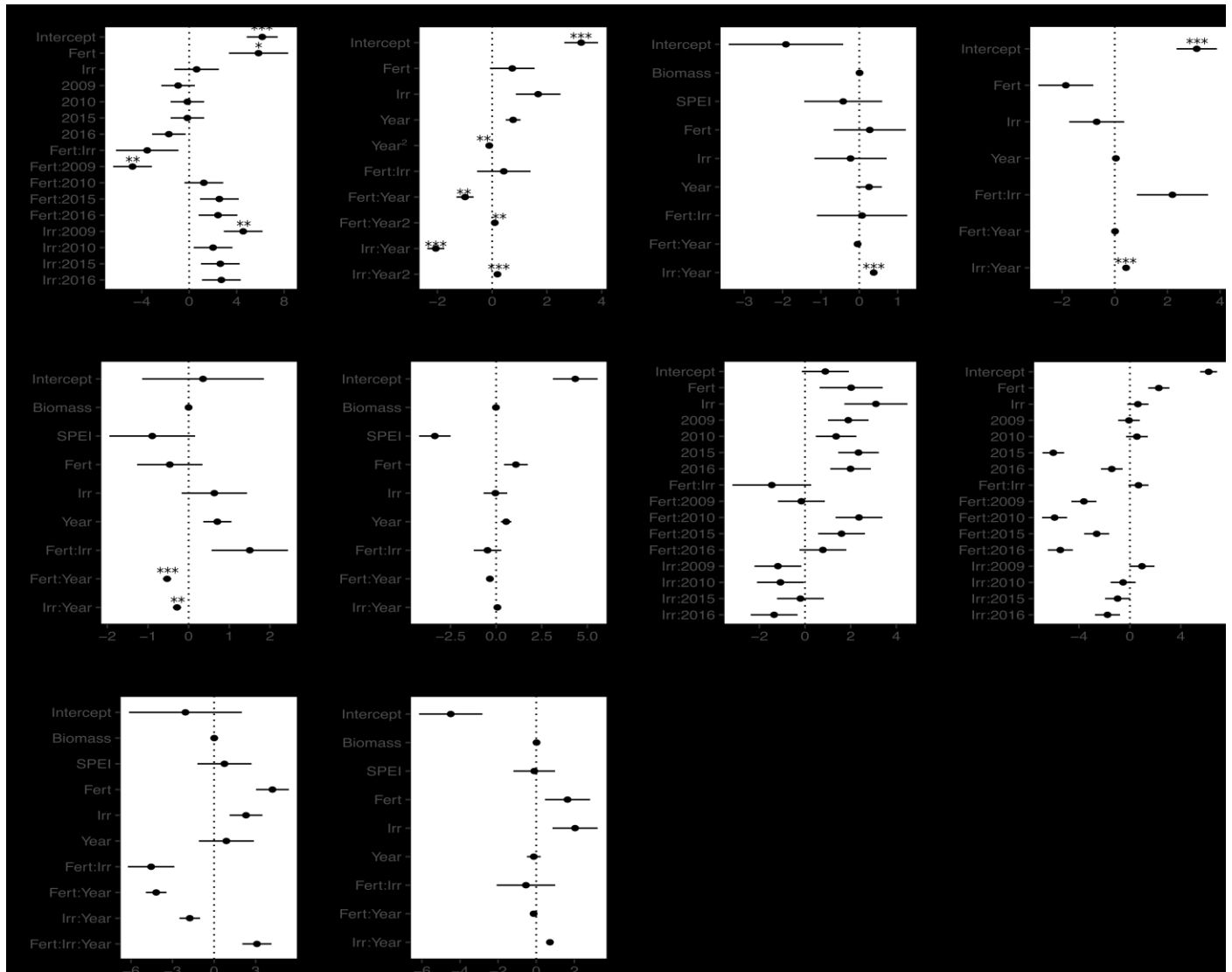


Figure S3. Most species responded in a gradual and continuous manner to either irrigation or fertilization. Output from mixed effects models showing the impact of the fertilization and irrigation treatments on community metrics (panels) through time. The y-axis corresponds to model parameters: SPEI is the standardized precipitation evapotranspiration index, Biomass is the average biomass across all plots for that year, Year corresponds to duration of experiment (0 = 2007, 9 = 2016), † in the year row indicates that the model was fit to the log of year, Fert is the nitrogen addition treatments and Irr is the irrigation treatments. The x-axis is the effect size and error bars are standard errors, or in the case of functional distance, 95% confidence intervals. *- $p < 0.05$, ** - $p < 0.01$, *** - $p < 0.001$. Species abbreviations are as follows - AG: *Andropogon gerardii*, BG: *Bouteloua gracilis*, CP: *Coreopsis palmata*, DP: *Dalea purpurea*, LA: *Liatriis aspera*, LP: *Lupinus perennius*, PP: *Poa parentis*, SN: *Sorghastrum nutans*, SR: *Solidago rigida*, SS: *Schizachryum scoparium*.

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