Ecosphere

Disentangling climate from soil nutrient effects on plant biomass production using a multispecies phytometer

Appendix S2 – Supporting Information

Peter A. Wilfahrt, Andreas H. Schweiger, Nelson Abrantes, Mohammed A.S. Arfin-Khan, Michael Bahn, Bernd J. Berauer, Michael Bierbaumer, Ika Djukic, Marleen van Dusseldorp, Pia Eibes, Marc Estiarte, Andreas von Hessberg, Petr Holub, Johannes Ingrisch, Inger Kappel Schmidt, Lazar Kesic, Karel Klem, György Kröel-Dulay, Klaus S. Larsen, Krista Lõhmus, Pille Mänd, Ildikó Orbán, Sasa Orlovic, Josep Peñuelas , David Reinthaler, Dajana Radujković, Max Schuchardt, Julienne M.-I. Schweiger, Srdjan Stojnic, Albert Tietema, Otmar Urban, Sara Vicca, Anke J. Jentsch

Table S1 – Linear mixed effect model of aridity, N and P availability as predictors of biomass production in local soil for phytometer communities and for each component species. N:P availability was run in a separate model with aridity; displayed aridity model results are from the model with N and P availability. Sites were used as random effects. R^2 values are semi-partial pseudo-R^2 values or estimates of the variance explained by the fixed effect when all other fixed effects are held constant. **Bold** rows indicate significance at p < 0.05 and *italic* rows show marginally significance (p < 0.1).

Effect	*DF*	*F value*	*P value*	*R2*
	Community biomass response			
Aridity	**1/10.96**	**30.89**	**< 0.001**	**0.81**
Phosphorus	**1/10.97**	**8.96**	**0.012**	**0.55**
Nitrogen	1/11.01	0.05	0.836	0.0059
N:P	*1/11.98*	*3.23*	*0.097*	*0.35*
	Dactylis glomerata biomass response			
Aridity	*1/10.99*	*4.57*	*0.056*	*0.52*
Phosphorus	1/10.99	1.7	0.219	0.29
Nitrogen	1/11.01	0.08	0.788	0.017
N:P	11.99	0.56	0.47	0.12
	Plantago lanceolata biomass response			
Aridity	1/10.99	2.26	0.161	0.34
Phosphorus	1/10.99	0.39	0.543	0.082
Nitrogen	1/11.01	0	0.948	0.00098
N:P	1/11.99	0.3	0.596	0.059
	Trifolium pratense biomass response			
Aridity	**1/10.90**	**49.69**	**< 0.001**	**0.78**
Phosphorus	**1/10.91**	**15.25**	**0.002**	**0.52**
Nitrogen	1/11.01	0.06	0.814	0.004
N:P	*1/11.97*	*4.66*	*0.052*	*0.32*

Table S2 – Linear mixed effect model of aridity, N and P availability as predictors of biomass production in standard substrate for phytometer communities and for each component species. N:P availability was run in a separate model with aridity; displayed aridity model results are from the model with N and P availability. Sites were used as random effects. R^2 values are semi-partial pseudo-R^2 values or estimates of the variance explained by the fixed effect when all other fixed effects are held constant. **Bold** rows indicate significance at $p < 0.05$ and *italic* rows show marginally significance ($p < 0.1$).

Effect	*DF*	*F value*	*P value*	*R2*
	Community biomass response			
Aridity	**1/10.97**	**13.17**	**0.004**	**0.59**
Phosphorus	1/10.90	0.25	0.629	0.027
Nitrogen	1/10.99	0.73	0.411	0.072
N:P	1/12.02	1.46	0.25	0.12
	Dactylis glomerata biomass response			
Aridity	*1/11.04*	*4.18*	*0.066*	*0.37*
Phosphorus	1/10.99	2	0.185	0.22
Nitrogen	1/11.06	0.11	0.741	0.015
N:P	1/12.09	0.06	0.812	0.0084
	Plantago lanceolata biomass response			
Aridity	1/10.99	0.21	0.655	0.058
Phosphorus	1/10.97	0.67	0.431	0.17
Nitrogen	1/10.99	0.02	0.897	0.005
N:P	1/12.00	0.04	0.842	0.012
	Trifolium pratense biomass response			
Aridity	**1/10.97**	**9.9**	**0.009**	**0.56**
Phosphorus	1/10.92	0.63	0.443	0.078
Nitrogen	1/11.00	1.29	0.281	0.14
N:P	1/12.02	2.2	0.164	0.2

Table S3 – Linear mixed effect model of aridity, N and P availability as predictors of climate corrected biomass production for phytometer communities and for each component species. N:P availability was run in a separate model with aridity; displayed aridity model results are from the model with N and P availability. Sites were used as random effects. R^2 values are semi-partial pseudo-R^2 values or estimates of the variance explained by the fixed effect when all other fixed effects are held constant **Bold** rows indicate significance at $p < 0.05$ and *italic* rows show marginally significance ($p < 0.1$).

Effect	*DF*	*F value*	*P value*	*R^2*
	Community biomass response			
Aridity	1/10.98	0.03	0.866	0.0061
Phosphorus	**1/10.98**	**8.13**	**0.016**	**0.63**
Nitrogen	1/11.01	0.57	0.467	0.1
N:P	*1/13.00*	*3.46*	*0.086*	*0.47*
	Dactylis glomerata biomass response			
Aridity	1/11.00	0.11	0.749	0.036
Phosphorus	1/11.00	1.38	0.265	0.32
Nitrogen	1/11.01	0.47	0.506	0.14
N:P	1/13.01	2.71	0.124	0.45
	Plantago lanceolata biomass response			
Aridity	1/10.99	0.94	0.353	0.14
Phosphorus	1/11.00	2.79	0.123	0.32
Nitrogen	1/11.03	0.11	0.746	0.018
N:P	*1/13.02*	*3.31*	*0.092*	*0.37*
	Trifolium pratense biomass response			
Aridity	1/10.99	0.01	0.922	0.0039
Phosphorus	1/10.99	1.94	0.191	0.43
Nitrogen	1/11.00	0.82	0.386	0.23
N:P	1/12.99	0.19	0.671	0.068

Table S4 Negative binomial model of climate, N availability and P availability on observed individual mortality

	Local Soil				Standard Substrate			
Predictor	Estimate (Incident Rate Ratio)	Standard Error	Z value	P value	Estimate (Incident Rate Ratio)	Standard Error	Z value	P value
Intercept	**-2.69 (0.07)**	**0.88**	**-3.07**	**0.002**	**-4.97 (0.01)**	**1.04**	**-4.78**	**< 0.001**
Aridity	**0.02 (1.02)**	**0.01**	**3.12**	**0.002**	**0.03 (1.03)**	**0.01**	**3.87**	**< 0.001**
Nitrogen	-1.3 (0.27)	0.87	-1.49	0.136	0.09 (1.09)	0.74	0.12	0.901
Phosphorus	-1.54 (0.21)	1.13	-1.36	0.173	0.91 (2.48)	1.32	0.69	0.49

Table S5 Beta distribution model of climate, N availability and P availability on the percentage of brown plant biomass observed

	Local Soil				Standard Substrate			
Predictor	Estimate (back-transformed)	Standard Error	Z value	P value	Estimate (back-transformed)	Standard Error	Z value	P value
Intercept	**-1.948 (0.14)**	**0.402**	**-4.85**	**< 0.001**	**-2.447 (0.09)**	**0.323**	**-7.57**	**< 0.001**
Aridity	**0.005 (1.01)**	**0.002**	**2.64**	**0.008**	**0.007 (1.01)**	**0.001**	**4.67**	**< 0.001**
Nitrogen	0.197 (1.22)	0.403	0.49	0.626	-0.887 (0.41)	0.533	-1.67	0.096
Phosphorus	-0.001 (1.00)	0.344	0	0.997	-0.052 (0.95)	0.284	-0.18	0.854

Table S6 Linear mixed-effects models of aridity, N availability and P availability on root:shoot with site as random effect

	Local Soil				Standard Substrate			
Predictor	Estimate	DF	F value	P value	Estimate	DF	F value	P value
Aridity	1.24×10^{-5}	1/10.9	1.58	0.235	7.26×10^{-6}	1/11.0	1.1	0.317
Nitrogen	-2.4×10^{-4}	1/11.0	0.02	0.885	0.00062	1/11.0	0.25	0.627
Phosphorus	-6.6×10^{-4}	1/10.9	0.13	0.728	-0.00284	1/10.9	1.57	0.237

Table S7: Effects of climate, PRS probe ion adsorption (nutrient availability), and soil properties on community and species-specific biomass production in local soil phytometers. Estimated effects are the result of model averaging of all mixed-effects models within 2 AICc of the best-fit model; predictors with a p-value below 0.05 following model averaging are bolded. All models used site as a random effect. Values in parentheses are the semi-partial pseudo-R^2 of a variable in a model fit with all predictors selected in model selection (i.e. those with estimated effects) to give an estimate of importance in these models. Pseudo-R^2 values are calculated *sensu* Nakagawa and Schielzeth (2013).

	Community	***Dactylis glomerata***	***Plantago lanceolata***	***Trifolium pratense***
Model Pseudo-R^2	0.916	0.635	0.778	0.888
Intercept	0.0027	0.011	0.0014	0.0008
Aridity	**-0.47(0.444)**	-	0.051(0.0326)	**-0.86(0.648)**
Soil GDD	**-0.49(0.366)**	**-0.59(0.395)**	**-0.98(0.512)**	0.063(0.0141)
N availability	0.019(0.0401)	0.02(0.0404)	0.019(0.0234)	0.0069(0.005)
P availability	**0.53(0.489)**	**0.51(0.426)**	0.32(0.126)	**0.27(0.189)**
K availability	-	-0.02(0.00669)	-0.18(0.121)	**0.18(0.177)**
Mg availability	**-0.24(0.158)**	-	**-0.84(0.506)**	-
S availability	0.021(0.00289)	-	-0.14(0.0384)	-
Ca availability	0.027(0.0129)	-	**0.61(0.247)**	-0.019(0.0179)
Soil pH	**0.31(0.234)**	0.047(0.0538)	**0.45(0.245)**	0.098(0.0602)
Initial Biomass	-0.021(0.0209)	-	-0.17(0.136)	-

Table S8. Effects of climate, PRS probe ion adsorption (nutrient availability), and methodological covariates on community and species-specific biomass production in standard soil phytometers. Estimated effects are the result of model averaging of all mixed-effects models within 2 AICc of the best-fit model; predictors with a p-value below 0.05 following model averaging are bolded. All models used site as a random effect. Values in parentheses are the semi-partial pseudo-R^2 of a variable in a model fit with all predictors selected in model selection (i.e. those with estimated effects) to give an estimate of importance in these models. Pseudo-R^2 values are calculated *sensu* Nakagawa and Schielzeth (2013).

	Community	***Dactylis glomerata***	***Plantago lanceolata***	***Trifolium pratense***
Model Pseudo-R^2	0.681	0.678	0.547	0.769
Intercept	0.0063	0.0057	-0.0026	0.0057
Aridity	**-0.48(0.294)**	**-0.96(0.601)**	-0.28(0.0902)	-
Soil GDD	**-0.45(0.28)**	-	-0.048(0.0716)	**-0.55(0.423)**
N availability	-0.035(0.105)	-0.071(0.0741)	-0.052(0.18)	-
P availability	0.12(0.18)	0.22(0.109)	-	**0.45(0.282)**
K availability	-0.12(0.0952)	**-0.86(0.477)**	-0.13(0.0769)	-0.069(0.0404)
Mg availability	-0.034(0.0216)	-	-0.39(0.0422)	**0.71(0.209)**
S availability	-	0.28(0.135)	0.6(0.264)	**-0.76(0.455)**
Ca availability	-0.011(0.00823)	-	0.066(0.189)	**-0.38(0.271)**
Initial Biomass	-	**0.5(0.35)**	-0.024(0.166)	0.025(0.0424)

Table S9. Effects of climate, PRS probe ion adsorption (nutrient availability), and methodological covariates on climate-corrected community and species-specific biomass production (local soil values after subtracting mean biomass production of the standardized substrate phytometers). Estimated effects are the result of model averaging of all mixed-effects models within 2 AICc of the best-fit model; predictors with a p-value below 0.05 following model averaging are bolded. All models used site as a random effect. Values in parentheses are the semi-partial pseudo-R^2 of a variable in a model fit with all predictors selected in model selection (i.e. those with estimated effects) to give an estimate of importance in these models. Pseudo-R^2 values are calculated *sensu* Nakagawa and Schielzeth (2013).

	Community	***Dactylis glomerata***	***Plantago lanceolata***	***Trifolium pratense***
Model Pseudo-R^2	0.756	0.74	0.697	0.801
Intercept	-0.0074	-0.0028	-0.0011	-0.009
Aridity	0.045(0.0118)	**1(0.481)**	0.2(0.176)	**-0.51(0.298)**
Soil GDD	0.061(0.0524)	**-0.85(0.264)**	-0.055(0.0867)	**0.9(0.577)**
N availability	0.017(0.0265)	-0.028(0.0331)	-	**0.31(0.214)**
P availability	**0.93(0.407)**	**0.83(0.415)**	**0.7(0.485)**	**0.56(0.344)**
K availability	**-0.44(0.28)**	**-0.61(0.477)**	**-0.54(0.447)**	-
Mg availability	**-0.48(0.13)**	-	-0.077(0.0922)	-0.29(0.107)
S availability	0.23(0.105)	-	-	**0.69(0.413)**
Ca availability	0.11(0.0138)	0.069(0.0637)	-	-0.15(0.0343)
Soil pH	-0.039(0.119)	-0.072(0.106)	**-0.55(0.246)**	-
Initial Biomass	-0.034(0.0198)	**-0.54(0.387)**	-0.047(0.0763)	**0.3(0.185)**

Table S10-12 – Output of mixed effect, linear regression models used to explore two-way interactions between climate and soil fixed effects in local, standard, and corrected biomass data. Site was used as a random effect. No model simplification approach was used here, explaining the disparity between significance levels of simplified models presented in the main text.

Table S10 Local soil interaction model

Predictor	F value	P value
Aridity	0.05	0.825
Soil Growing Degree Days (GDD)	2.11	0.196
P availability	0.44	0.533
N availability	0.31	0.598
Aridity x P availability	1.36	0.288
Aridity x N availability	0.01	0.945
GDD x P availability	0.02	0.884
GDD x N availability	0.16	0.705

Table S11 Standard substrate interaction model

Predictor	F value	P value
Aridity	2.52	0.164
Soil Growing Degree Days (GDD)	0.01	0.919
P availability	0.35	0.578
N availability	0.51	0.502
Aridity x P availability	0.49	0.511
Aridity x N availability	1.53	0.262
GDD x P availability	0.43	0.537
GDD x N availability	0.96	0.364

Table S12 Corrected Soil Effect

Predictor	F value	P value
Aridity	0	0.962
Soil Growing Degree Days (GDD)	0.12	0.744
P availability	0.03	0.871
N availability	1.38	0.285
Aridity x P availability	0.43	0.536
Aridity x N availability	2.17	0.191
GDD x P availability	0	0.99
GDD x N availability	1.79	0.23

Table S13 PRS probe adsorption values in the local soil in the last 10 days of the 50-day trial. All values are in micrograms absorbed per 10 cm^2.
*Site removed from analyses due to heavy herbivory.

Site Name	Nitrogen	Phosphorus	Potassium	Magnesium	Sulfur	Calcium
Antwerp	0.46	0.25	75.93	83.57	415.82	2373.16
Aveiro	4.94	0.41	18.4	5.23	10.38	34.52
Bayreuth	0.24	16.53	155.29	242.39	9.83	1788.71
Bílý Kříž	10.04	0.48	52.72	83.58	71.28	425.91
Brandbjerg*	7.02	0.45	80.83	14.73	9.01	47.39
Domanínek	6.23	2.98	91.67	30.21	10.85	256.88
Esterberg	7.12	3.14	13	680.24	16.04	2299.04
FAHM	3.6	1.11	27.91	47	15.61	271.91
Fendt	0.6	3.42	19.05	195.93	11.21	1747.3
GARRAF	27.36	0.89	51.24	36.08	5.1	74.5
Graswang	0.64	1.18	11.3	766.67	8.92	2411.28
Gumpenstein	4.56	32.77	63.1	166.48	26.71	1676.46
Kacka Suma	43.78	0.58	59.99	195.9	24.68	1690.32
Kiskunság	6.98	0.78	52.06	60.39	8.94	580.1
Mols	8.7	0.25	47.62	11.27	11.76	42.66
Oldebroek	11.06	0.5	120.14	12.52	9.61	26.93
Waldstein*	0.5	10.41	90.1	146.56	14.66	1155.48
Zöbelboden*	4.32	0.42	23.72	346.06	12.95	1596.02

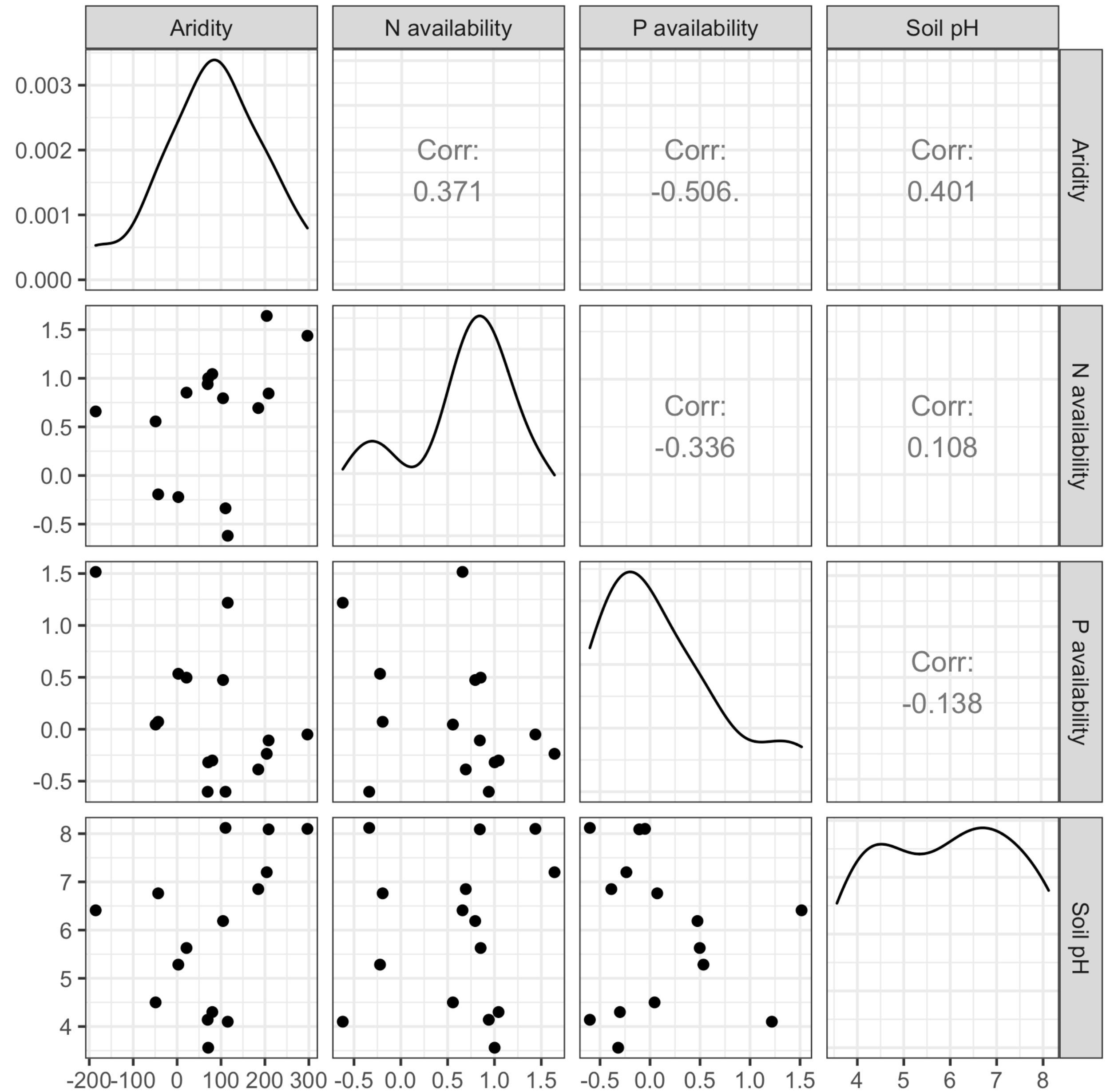

Figure S1 – Matrix of relationship between aridity, N availability, P availability, and soil pH in the local soils of each site. Diagonals show a density plot of the distribution of data. No significant relationships between soil variables were detected.

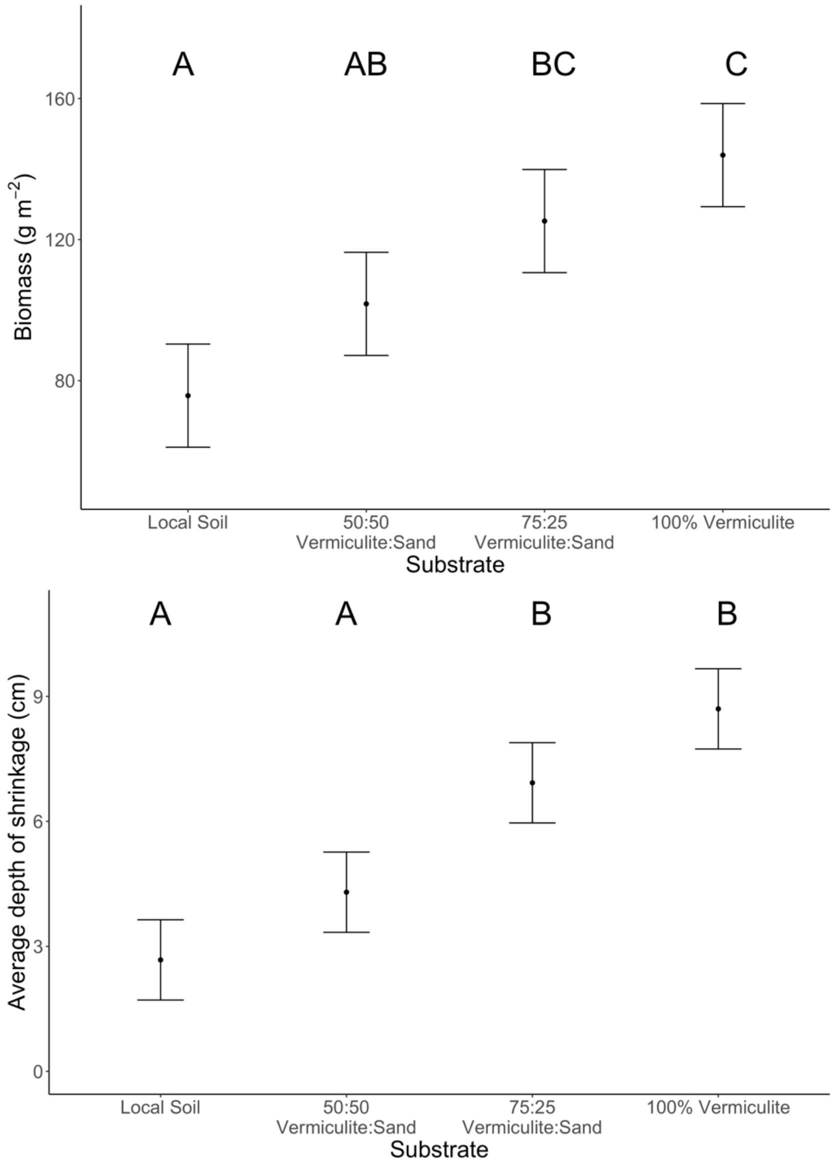

Figure S2 – We tested whether mixing chemically inert quartz sand with vermiculite would help mitigate the subsidence issue we observed in the standard substrate (100% vermiculite) of our 2017 phytometer trial. On July 7th, 2018, we tested twenty phytometers at the University of Bayreuth Botanical Garden with four different substrate compositions: local soil, 100% vermiculite, a 50:50 vermiculite to sand ratio by volume, and a 75:25 vermiculite to sand ratio by volume. The protocol was identical in every other way to the 2017 trial. Subsidence of the 50:50 mixture was statistically indistinguishable from the local soil, while the 75:25 and 100% vermiculite mixtures had 2-3 times more subsidence. The 75:25 and 100% mixture also had higher biomass growth over this time period than the 50:50 mixture and local soil, indicating that the 50:50 mixture potentially mitigates the high-water retention of vermiculite. This high water retention may have dampened observable aridity effects in our 2017 trial.