Supplementary Material

Evaluating the resilience of soil moisture dynamics to drought periods as function of soil type and climatic region

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Contents

In Figure S1 the model performance and soil water characteristics curve of the lysimeter used for model training is shown (soil material from Dedelow transported to Bad Lauchstädt). Figure S2 shows an illustrative example of a lysimeter adapting the response function to the drier climatic conditions. Figure S3 depicts an example of good general model performance deflecting from a systematic trend of error metrics and shift in the soil moisture response function. Text S1, Table S1, and Figures S4 to S7 present the model results using soil moisture classification (wet', moderate', dry') based on the water content statistics calculated for each lysimeter (in the main text the classification was deduced from data of the lysimeter used for training).

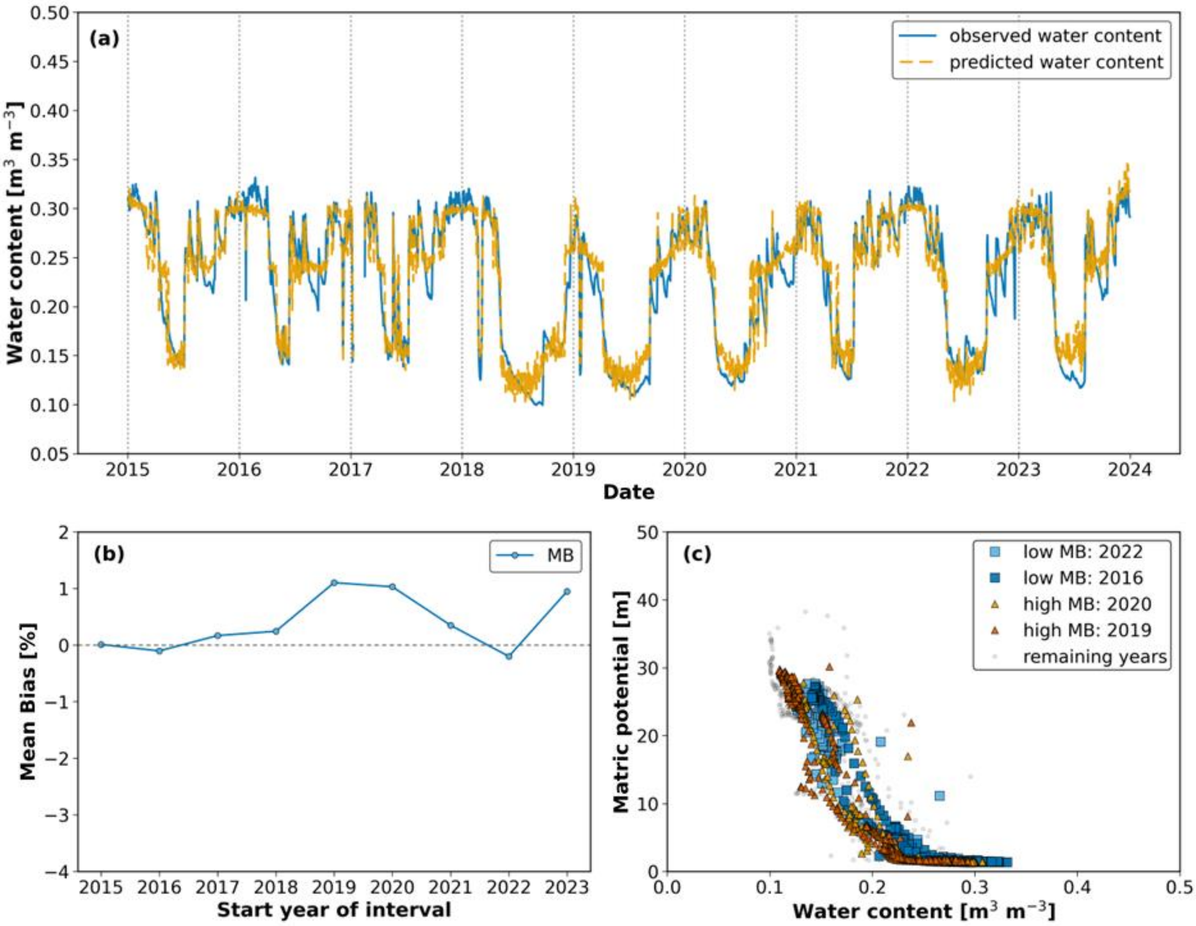

Figure S1. *The Dedelow-origin lysimeter relocated to Bad Lauchstädt was used as the reference site to calibrate the soil moisture response function. Data from January 2015–December 2023 were split into training (70%) and validation (30%)(a) Observed and predicted water content show close agreement during calibration and validation (b) Yearly mean bias (MB) remains close to zero with minor fluctuations. (c) Soil water retention data demonstrate that the difference between years with low MB (e.g., 2016, 2022) and high MB (e.g., 2019, 2020) is minimal, indicating that the response function at the training site remained stable over time.*

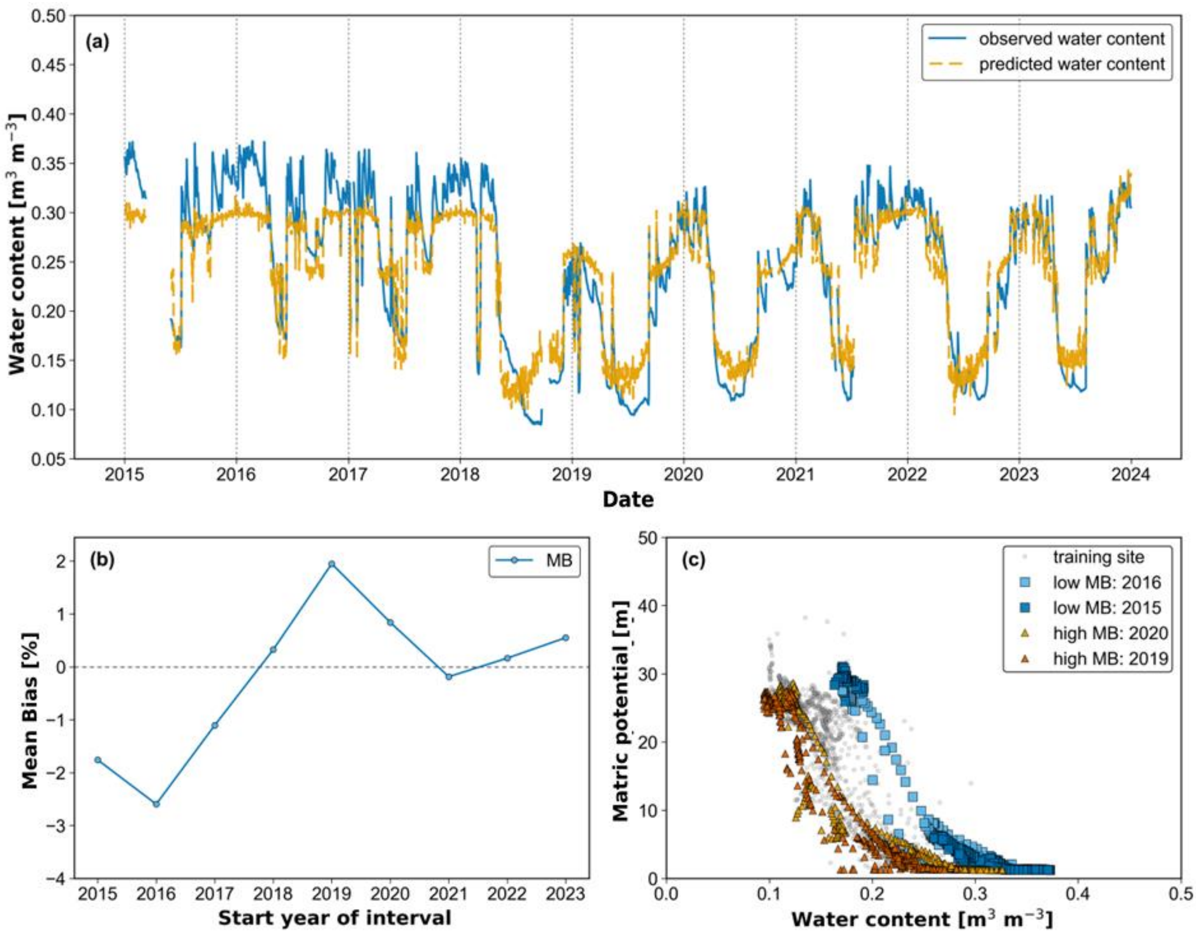

Figure S2. *Selhausen-origin soil relocated from the humid climate in Selhausen to the drier continental climate at Bad Lauchstädt. After 2018, predictions and observations (a) converged more strongly, with mean bias (MB) stabilizing near zero (b), indicating that the soil response functions shifted toward adjustment to the drier climate. (c) The soil water retention data show the shift from high water contents to lower water contents that are similar to the observations at the training site.*

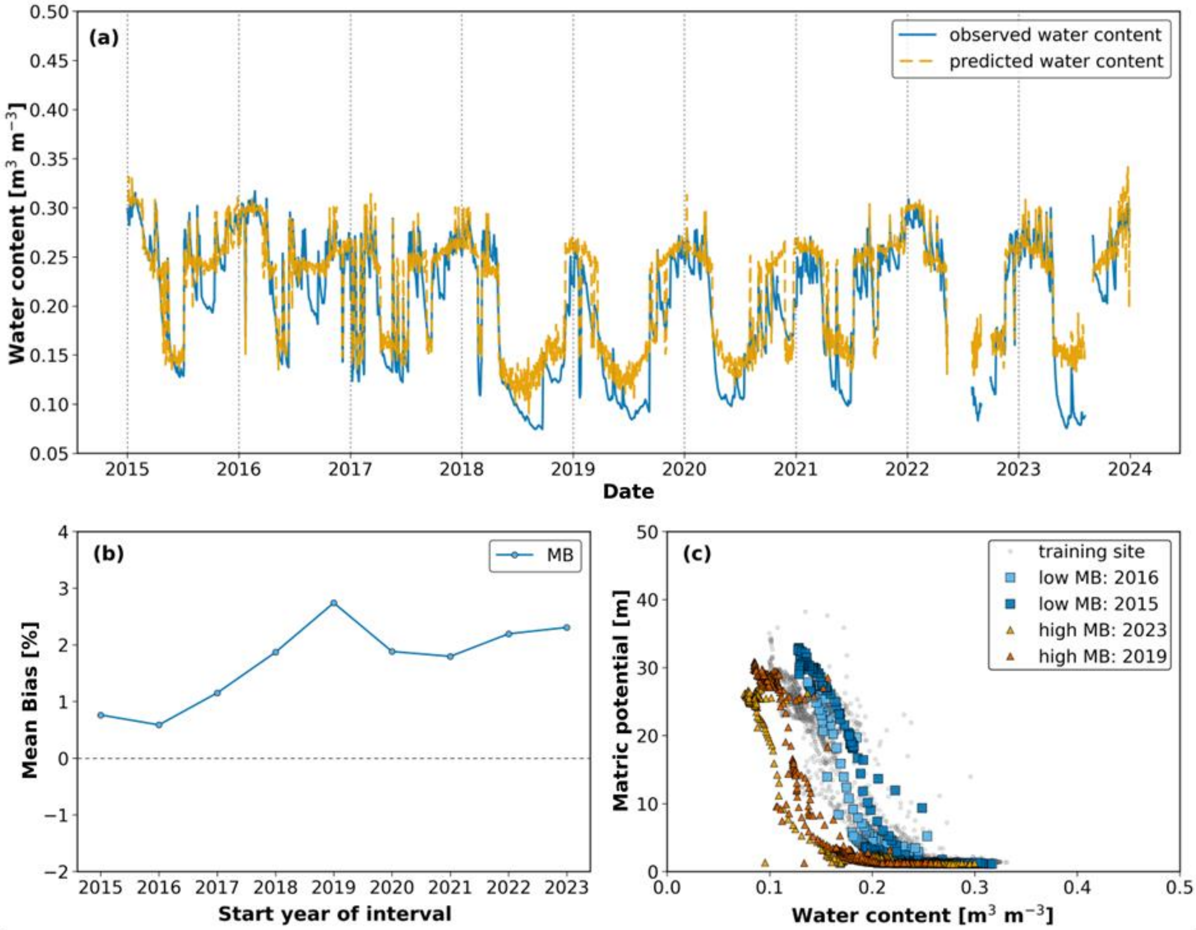

Figure S3. *Dedelow-origin soils relocated to Bad Lauchstädt. The predictions (a) maintained high NSE values (0.79) but the mean bias (MB) increased over time (b), with soil water retention data from the selected years reflecting this progressive change to lower water contents (c).*

Text S1: Model predictions based on soil specific soil moisture classification

In the main manuscript, percentile thresholds to classify daily water content into the three classes (‘wet’, ‘moderate’, ‘dry’) were derived from the Dedelow training site and applied uniformly across all prediction sites. With this choice, no information on the soil moisture statistics for the other lysimeters were required and shifts in the soil moisture response function could be compared relative to the training reference. However, because the range of water contents vary with soil texture (and structure), a value assigned as ‘wet’ in the sandy loam from Dedelow may be relatively dry for the silt loam at the other sites. To account for soil specific differences, the measured water content values θ of each lysimeter were normalized by $(\theta-\theta_{min})/(\theta_{max}-\theta_{min})$ with minimum θ_{min} and maximum θ_{max} value of the time series for each lysimeter. The 30%- and 70%-quantiles of the normalized values were then used to define a measured water content as ‘dry’, ‘moderate’ and ‘wet’. The overall classification of the soil moisture response function (‘stable’, ‘resilient’, ‘changed’) based on the normalized water contents remained nearly identical, with only three out of 24 lysimeters differing (Table S1), confirming that our conclusions are independent of the classification scheme. However, with such site-specific scaling we cannot define the location of the SWRC relative to the training site, since the training reference is no longer preserved, which is another reason that the individual scaling was not used in the main text.

Table S1: Resilience of soil moisture response function for the four soil materials transported to Bad Lauchstädt and Selhausen. In contrast to Table 1 in the main text, the classification of soil water content in three classes (wet, moderate, dry) was done individually for each lysimeter (and not based on the lysimeter from Dedelow used in the training). The 'type' describes the class of response function of the individual lysimeters (S for 'stable', R for 'resilient' and C for 'changed'). Only three out of 24 lysimeters obtained a different classification (highlighted by asterisk*). The 'drift' is the average value $|MB_{2023}-MB_{2015}|$ of the three lysimeters with the difference in Mean Bias (MB) between years 2023 and 2015. The 'amplitude' is the maximum difference of the MBs between the first year (2015) and the years between 2018 and 2022 (denoted as year 20xx).

	Located at Bad Lauchstädt			Located at Selhausen		
	Type	Drift	Amplitude	Type	Drift	Amplitude
Dedelow	S,ℝ,C	0.89	1.63	ℝ,C,C	1.10	1.96
Bad Lauchstädt	S,S,ℝ	0.63	1.14	ℝ,C,C	1.47	2.23
Sauerbach	S*,ℝ*,C	0.87	2.28	C,C,C	2.45	3.58
Selhausen	ℝ*,ℝ,C	1.08	2.15	S,S,ℝ	0.71	1.18

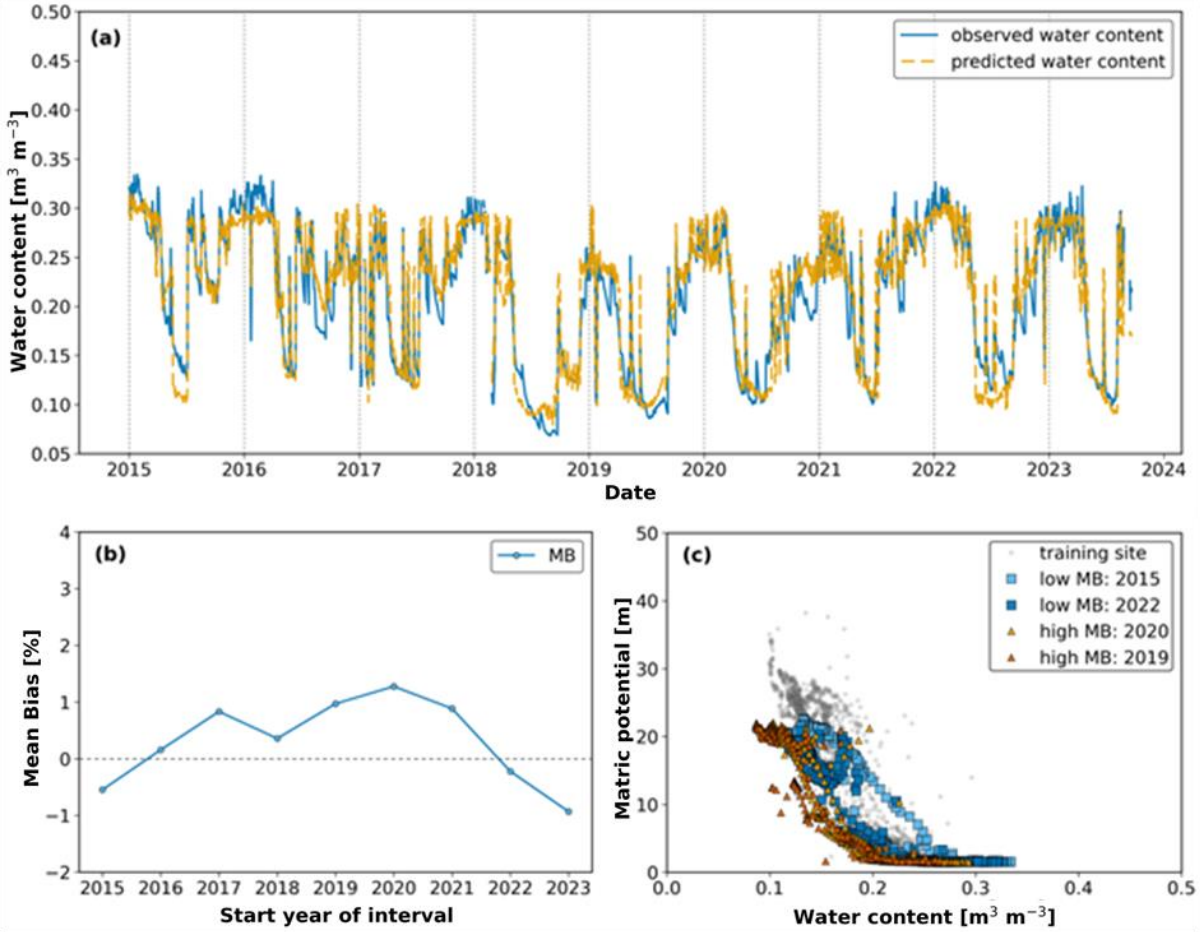

Figure S4. *Analysis of soil moisture dynamics (2015–2023) for a Dedelow-origin lysimeter tested at Bad Lauchstädt. Panel (a) shows the time series of observed (blue) and predicted (orange) water content. Compared to the figure in the main text (Fig. 5a), the fit during the dry years is better. The NSE value increased from 0.84 in Figure 5a to 0.87. (b) The mean bias (MB) curve still shows a rising trend around 2019–2020 followed by a return towards the initial 2015 value, consistent with a 'resilient' response function. Panel (c) displays soil water retention data from the training site (grey) and from selected years representing different MB conditions and is identical to Figure 5c in the main text.*

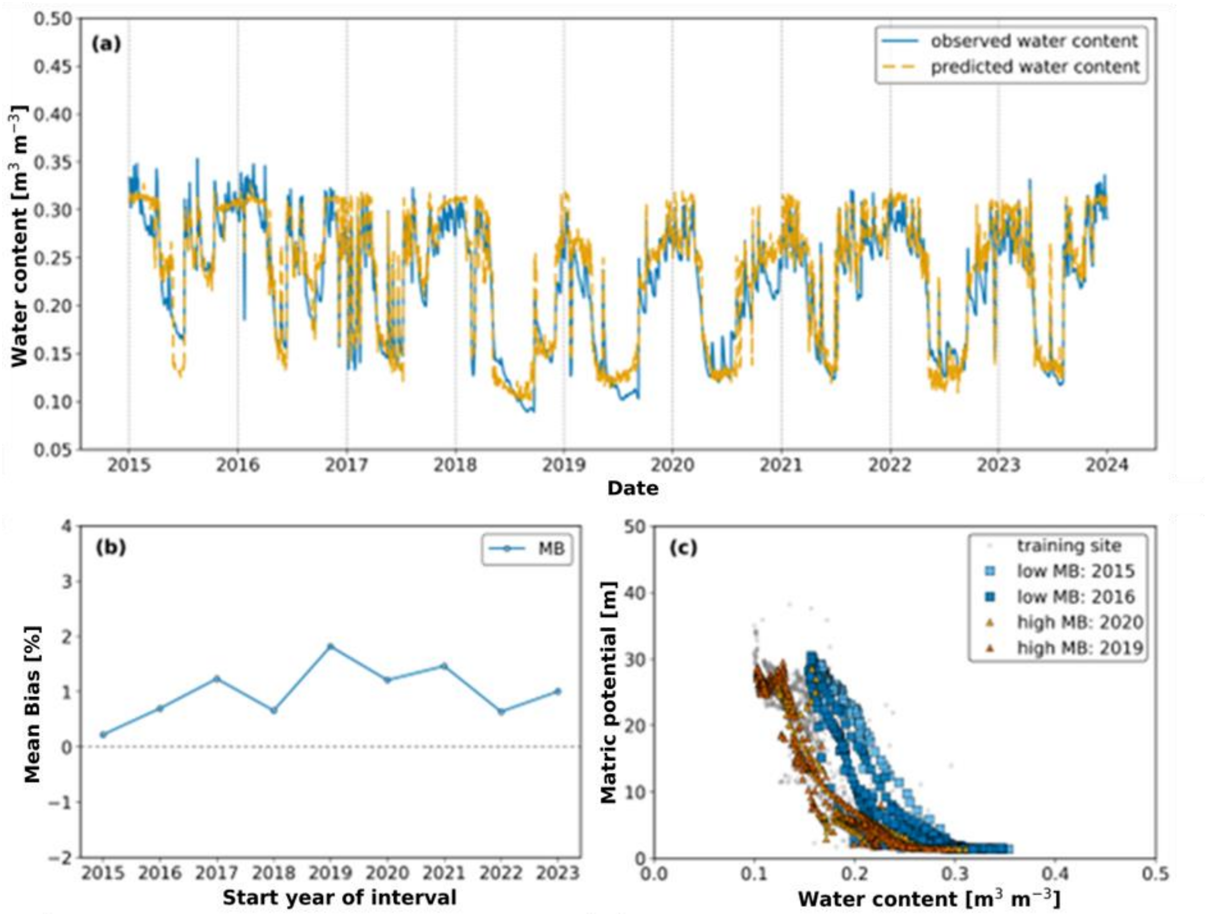

Figure S5. *Analysis of soil moisture dynamics (2015–2023) for a Bad Lauchstädt-origin soil lysimeter tested at Bad Lauchstädt. Comparison of measured (blue) and simulated (orange) daily water content values in (a) and mean bias (MB) in panel (b). Both figures are similar to Figure 6 in the main text, but with MB values that are consistently positive (predicted values slightly higher than measured values). The NSE value dropped from 0.88 in Figure 6a to 0.85. Panel (c) displays soil water retention data from the training site (grey) and from selected years representing different MB conditions and is identical to Figure 6c in the main text.*

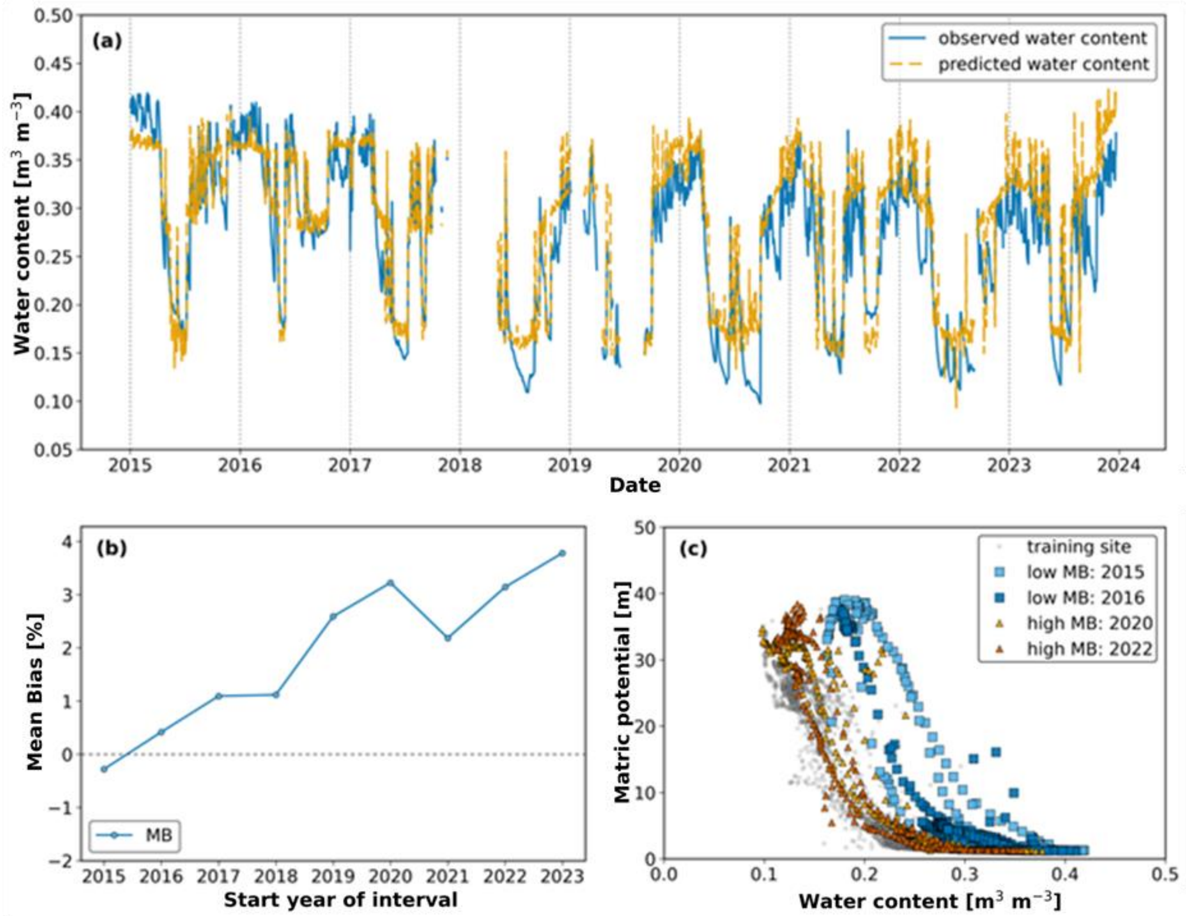

Figure S6. *Analysis of soil moisture dynamics (2015–2023) for Sauerbach-origin lysimeter relocated to Selhausen (a) Comparison of observed and predicted daily volumetric water content with better model agreement at the beginning of the observation period compared to Figure 7 in the main text. The NSE value increased from 0.74 in Figure 7a to 0.78 (b) The mean bias (MB) curve shows a steady rise from near zero in 2015 to strongly positive values by 2023, consistent with a 'changed' response function as in figure 7. Panel (c) displays soil water retention data from the training site (grey) and from selected years representing different MB conditions and is identical to Figure 7c in the main text.*

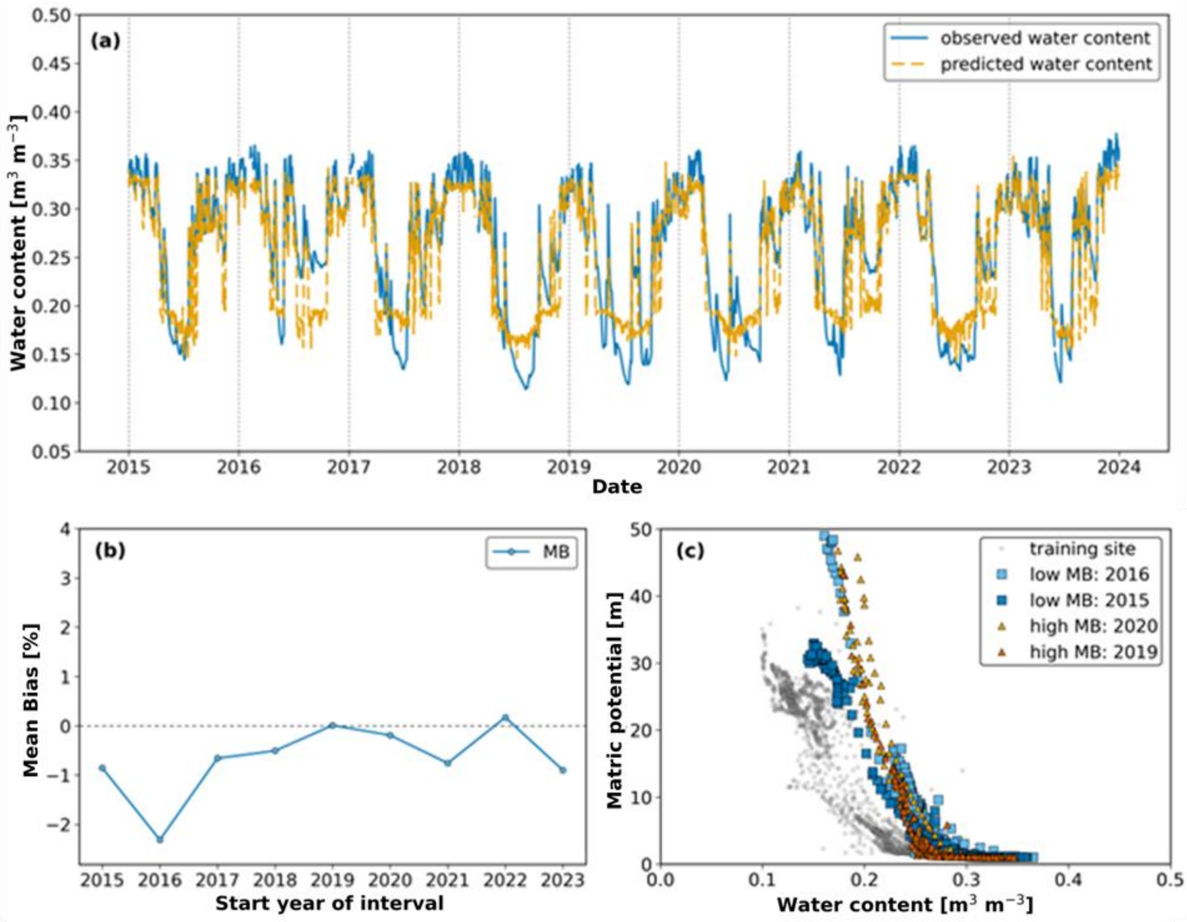

Figure S7. *Soil moisture dynamics (2015–2023) for a Selhausen-origin lysimeter tested at Selhausen. (a) In comparison to the main-text (figure 8a), the fit between observed (blue) and predicted (orange) water content improves in the saturated range but shows larger deviations at low water contents. The NSE value dropped from 0.86 in Figure 8a to 0.83. (b) The mean bias (MB) shows a similar trend as in 8b but with a more pronounced drop in 2nd half of year 2016 (underestimating the water content). Panel (c) displays soil water retention data from the training site (grey) and from selected years representing different MB conditions and is identical to Figure 8c in the main text.*