Supplement of

Effects of spatial soil moisture variability in forests plots on simulated groundwater recharge estimates

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Table S1 Model input parameters - preselected and fixed parameters based on the findings of sensitivity analyses as well as used ranges for calibration for the varied parameters based on literature, physical limits encountered and observed data from the study area, KH – Kienhorst plot, TH – Tharandt plot

Parameter	Definition	Unit	Fixed KH/TH	Lower Boundary KH/TH	Upper Boundary KH/TH
	Canopy characteristics				
alb	Albedo of soil/vegetation surface without snow	**(-)**	0.14/0.13		
albsn	Albedo of soil/vegetation surface with snow	(-)	0.3926/0.6		
cintrl	Maximum interception storage of rain per unit LAI	(mm)	0.15/0.07		
cintrs	Maximum interception storage of rain per unit SAI	(mm)	0.1526/0.1		
lwidth	Average leaf width	(cm)	0.019/0.003		
rhotp	Ratio of total leaf area to projected area	(-)	2.5/2.5		
frintlai	Intercepted fraction of rain per unit LAI	(-)	0.08/0.02		
frintsai	Intercepted fraction of rain per unit SAI	(-)	0.12/0.06		
cr	Extinction coefficient for photosy. active radiation in the canopy	(-)		0.5/0.5	0.7/0.7
ksnvp	Reduction factor to reduce snow evaporation	(-)		0.05/0.05	1/1
DOYBstart	Day of budburst for seasonal LAI evolution	(day of year)		110/110	150/150
	Vegetation hydraulics				
glmax	Maximum leaf vapour conductance when stomata are fully open	(m s^{-1})	0.0043/0.0069		
psicr	Critical leaf water potential at which stomates close	(MPa)	-2/-2		
r5	Solar radiation level at which leaf conductance is half of its value	(W m^2)	100/100		
mxkpl	Maximum internal conductivity for water flow through the plants	(mm d^{-1} MPa^{-1})	18.3/7.5		
fxylem	Fraction of internal plant resistance to water flow that is in the Xylem	(-)	0.7/0.3		
glmin	Minimum leaf vapour conductance when stomata are closed	(m s^{-1})	0.0003/0.0002		
cvpd	Vapor pressure deficit at which stomatal conductance is halved	(kPa)		0.5/0.5	2/2
	Root characteristics				
mxrtln	Maximum length of fine roots per unit ground area	(m m^{-2})	3000/1809		
betaroot	β param. of vertical root distribution	(-)		0.9/0.9	1.2/1.2
maxrootdepth	Maximum root depth	(m)		-1.7/-1.2	-0.2/-0.2
initrdep	Initial root depth	(m)	0.25/0.25		
initrlen	Initial water-absorbing root length per unit area	(m m^{-2})	12/31.41		
rgroper	Period of net root growth	(year)	18.29/18.29		
rgrorate	Vertical root growth rate	(m a^{-1})	0.268/0.268		
rtrad	Average radius of the fine or water-absorbing roots	(mm)	0.35/0.35		
	Soil processes				
rssa	Soil evaporation resistance (RSS) at field capacity	(s m^{-1})	500/500		
infexp	Infilt. exponent that determines distribution of infilt. water with depth	(-)		0.2/0.2	1/1
idepth	Soil depth until which infiltration is distributed	(m)		0.5/0.2	1.7/1
qffc	Quickflow fraction of infiltrating water at field capacity	(-)		0/0	0.5/0.5
qfpar	Quickflow shape parameter	(-)	1.07/0.5		
qdepth	Soil depth until which surface/source area flow is considered	(m)	1.7/0.8		
drain	Multiplier to partially activate drainage	(-)		0/0	1/1
length_slope	Slope length for downslope flow (DSFL)	(m)		50/0	800/500
bypar	Switch to turn byflow on (1) or off (0)	(-)	1/1		

	Soil hydraulics				
psiini	Initial pressure head of soil layers	(kPa)	-10/-10		
ths	Saturated volumetric soil moisture content	(-)		0.2/0.2	0.6/0.6
thr	Residual volumetric soil moisture content	(-)		0.01/0.01	0.035/0.19
alpha	Alpha parameter of the van Genuchten water retention function	(m^{-1})		1.2/2	3/4
npar	N parameter of the van Genuchten water retention function	(-)		1.3/1.3	2/2
ksat	Saturated hydraulic conductivity	(mm d^{-1})		895/150	10000/10000
tort	Tortuosity parameter of Mualem hydraulic conductivity function	(-)		0.5/0.5	1.5/1.5

Satistics

Evaluation of model performance

The Kling–Gupta efficiency (KGE), a metric used to evaluate the accuracy and quality of models that simulate hydrologic processes (Knoben et al., 2019) was used as model performance criteria. It enhances traditional efficiency measures by integrating three key statistical components: correlation, variability bias, and mean bias. The KGE provides a more balanced assessment of model performance by considering not only the strength of the linear relationship but also the distribution and scale differences between observed and simulated values and its formula was proposed by (Gupta et al., 2009):

$$KGE = 1 - \sqrt{(r-1)^2 + \left(\frac{\sigma_{sim}}{\sigma_{obs}} - 1\right)^2 + \left(\frac{\mu_{sim}}{\mu_{obs}} - 1\right)^2} \quad (2)$$

where σ_obs is the plotard deviation in observations, σ_sim the plotard deviation in simulations, μ_sim the simulation mean, and μ_obs the observation mean. Regarding the interpretation of KGE values, KGE = 1 signifies a perfect match between simulations and observations. A KGE value close to 1 reflects strong correspondence between simulated and observed data. However, KGE < 0 suggests that the mean of observations may provide more accurate estimates than simulations, indicating a poor fit (Castaneda-Gonzalez et al., 2018; Koskinen et al., 2017), where the model performs worse than using the mean as a prediction (Andersson et al., 2017; Schönfelder et al., 2017).

Variation of parameters

The coefficient of variation (CV) was computed as a normalized measure of dispersion. The CV, defined as the ratio of the plotard deviation to the mean, enables comparison of variability across parameters with different magnitudes and units. Parameters exhibiting elevated coefficient of variation (CV) values were recognized as highly variable, suggesting the need for detailed analysis of their impact on model performance and sensitivity (Fowler et al., 1998).

Kolmogorow Smirnov test

The Kolmogorov–Smirnov test (KS) is used to assess the agreement between two probability distributions based on the maximum deviation between two empirical cumulative distribution functions. It can be applied either to determine whether two samples originate from the same distribution (two-sample test) or whether a sample follows a specified theoretical distribution (one-sample test). In the two-sample case, the test statistic Dn, is defined as:

$$D_{n,m} = \sup_{x} |F_n(x) - G_m(x)| \quad (3)$$

where $F_n(x)$ and $G_m(x)$ are the empirical cumulative distribution functions of the two samples with with sizes n and m, and $\sup_x$ denotes the supremum (maximum) over all values of x.

The KS test makes no assumptions about the specific form of the underlying distributions, making it particularly well suited for continuous data with unknown distribution, as commonly found in hydrological or environmental studies. The null hypothesis $H0$ states that the two distributions are identical. If the test statistic exceeds the critical value, $H0$ is rejected at the chosen significance level α (Massey, 1951).

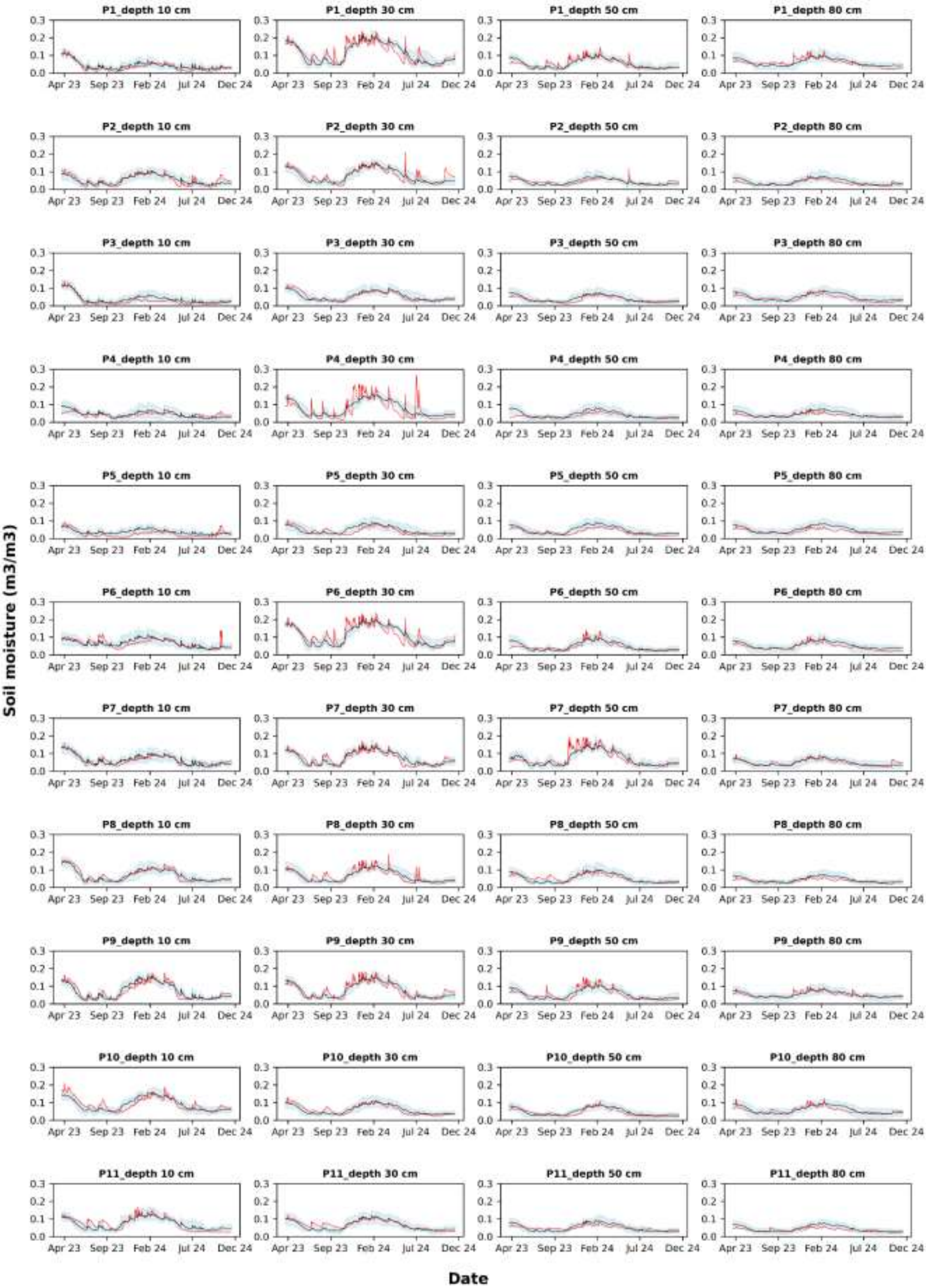

Figure S1 Observed versus simulated soil moisture for profile 1 to 11 at Kienhorst plot

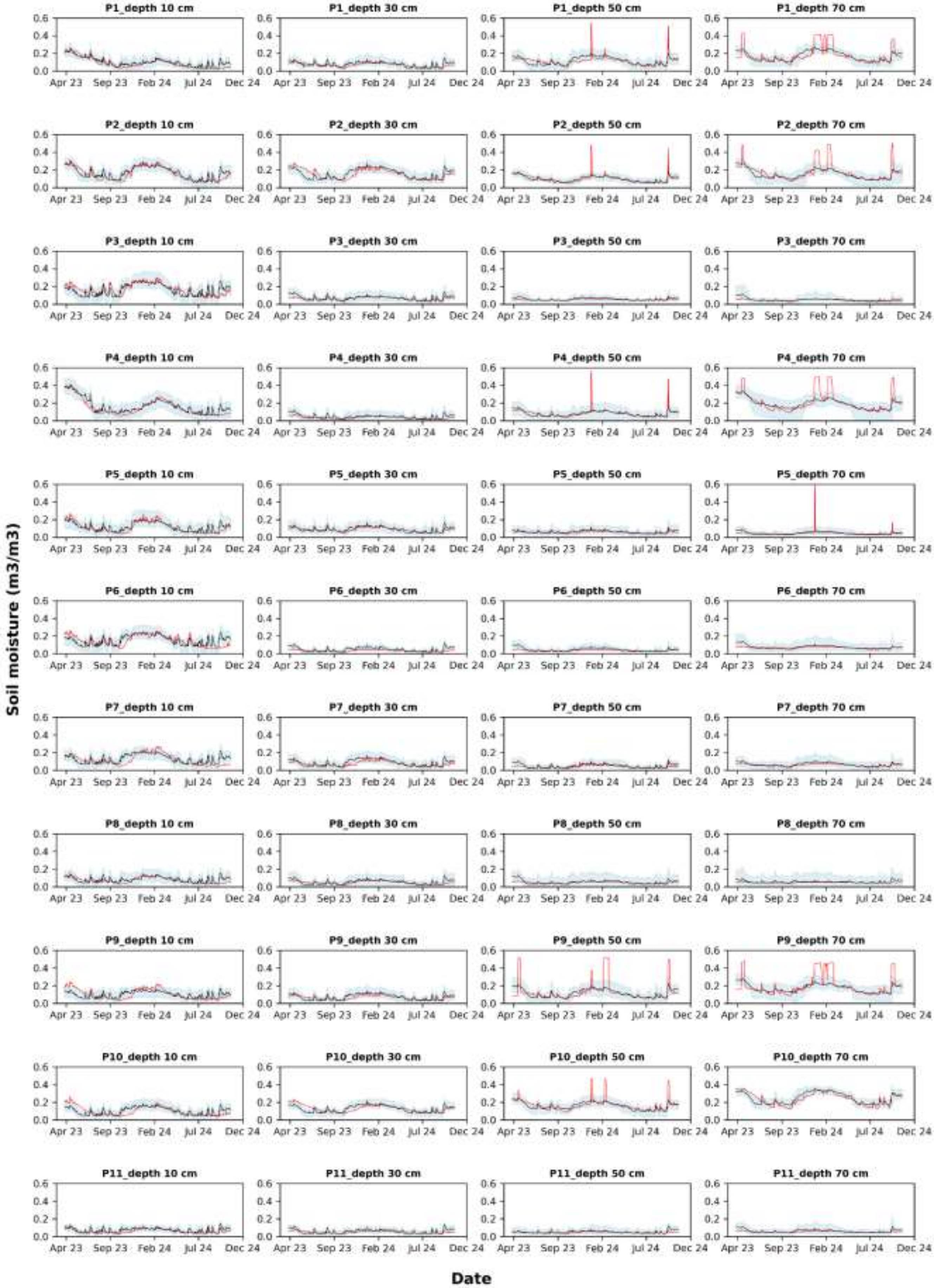

Figure S2 Observed versus simulated soil moisture for profile 1 to 11 at Tharandt plot

Table S2 Kling Gupta efficiency for agreement between observed and simulated soil moisture at Kienhorst plot

Depth	**P 1**	**P 2**	**P 3**	**P 4**	**P 5**	**P 6**	**P 7**	**P 8**	**P 9**	**P 10**	**P 11**
10 cm	0.74	0.78	0.64	0.29	0.38	0.69	0.91	0.87	0.91	0.82	0.76
30 cm	0.86	0.85	0.84	0.66	0.72	0.87	0.88	0.84	0.91	0.87	0.82
50 cm	0.85	0.60	0.79	0.22	0.56	0.83	0.82	0.74	0.82	0.85	0.36
80 cm	0.77	0.74	0.70	0.30	0.46	0.79	0.80	0.31	0.81	0.68	0.01

Table S3 Kling Gupta efficiency for agreement between observed and simulated soil moisture at Tharandt plot

Depth	**P 1**	**P 2**	**P 3**	**P 4**	**P 5**	**P 6**	**P 7**	**P 8**	**P 9**	**P 10**	**P 11**
10 cm	0.76	0.80	0.74	0.82	0.73	0.59	0.56	0.58	0.44	0.54	0.60
30 cm	0.57	0.74	0.36	0.35	0.70	0.34	0.56	0.49	0.42	0.64	0.01
50 cm	0.61	0.59	0.08	0.44	0.48	0.58	0.44	0.22	0.31	0.51	0.05
80 cm	0.49	0.48	0.39	0.46	0.16	0.41	0.65	0.33	0.32	0.84	0.41

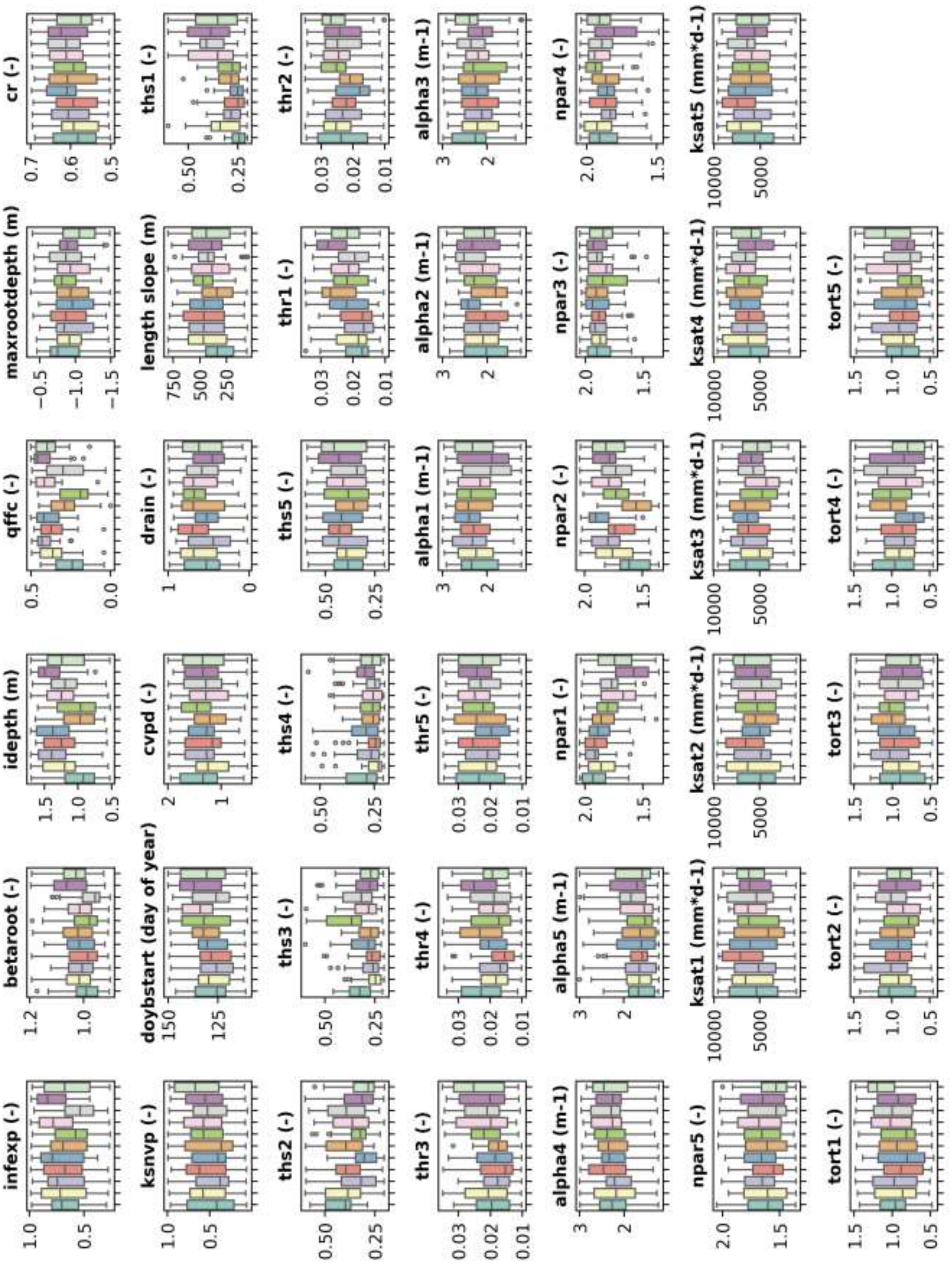

Figure S3 Variation of the input parameters for the individual 11 soil profiles each based on the 30 best simulations for Kienhorst plot

Figure S4 Variation of the input parameters in the individual 11 soil profiles each based on the 30 best simulations for Tharandt plot

Table S4 Determined parameter sets for Kienhorst plot for the best simulation related to KGE

	P 1	**P 2**	**P 3**	**P 4**	**P 5**	**P 6**	**P 7**	**P 8**	**P 9**	**P 10**	**P11**
infexp	0.67	0.77	0.82	0.28	0.82	0.36	0.29	0.68	0.79	0.89	0.26
betaroot	0.94	1.01	0.98	0.97	0.96	1.03	0.91	0.92	1.08	0.93	1.08
idepth	1.05	1.60	1.709	1.09	1.70	0.89	0.95	1.24	1.01	1.59	1.06
qffc	0.24	0.42	0.49	0.34	0.49	0.32	0.14	0.47	0.21	0.48	0.50
maxrootdepth	-0.65	-0.93	-1.41	-0.78	-1.41	-0.97	-0.80	-1.35	-0.48	-1.21	-0.95
cr	0.51	0.63	0.67	0.60	0.67	0.69	0.69	0.67	0.50	0.69	0.59
ksnvp	0.78	0.91	0.99	0.50	0.99	0.24	0.21	0.54	0.59	0.50	0.34
doybstart	134.7	136.1	114.6	137.6	114.6	138.1	131.1	143.1	140.8	124.9	134.8
cvpd	1.82	0.61	0.99	1.29	0.99	1.27	0.69	1.62	0.84	1.25	1.44
drain	0.13	0.64	0.90	0.96	0.90	0.76	0.63	0.21	0.75	0.04	0.52
length slope	179.9	464.0	538.2	299.8	538.2	524.9	379.8	152.7	636.2	305.0	768.6
ths1	0.24	0.45	0.30	0.21	0.30	0.36	0.33	0.53	0.37	0.27	0.51
ths2	0.33	0.39	0.49	0.32	0.49	0.47	0.36	0.25	0.33	0.60	0.28
ths3	0.35	0.32	0.25	0.20	0.25	0.37	0.57	0.27	0.21	0.51	0.27
ths4	0.24	0.43	0.48	0.22	0.48	0.26	0.21	0.33	0.21	0.30	0.32
ths5	0.54	0.44	0.29	0.25	0.29	0.25	0.57	0.59	0.52	0.53	0.47
thr1	0.016	0.021	0.015	0.018	0.015	0.031	0.026	0.032	0.012	0.029	0.021
thr2	0.032	0.022	0.026	0.023	0.026	0.020	0.013	0.033	0.019	0.019	0.026
thr3	0.018	0.021	0.024	0.021	0.024	0.016	0.031	0.020	0.034	0.030	0.018
thr4	0.023	0.019	0.017	0.012	0.017	0.025	0.020	0.021	0.021	0.014	0.030
thr5	0.01	0.029	0.024	0.029	0.024	0.011	0.012	0.021	0.033	0.031	0.020
alpha1	2.58	2.84	2.64	2.10	2.64	2.66	1.97	2.86	1.31	1.54	2.08
alpha2	2.53	1.90	2.49	1.86	2.49	2.45	2.08	1.45	2.71	2.24	1.61
alpha3	2.00	2.48	2.57	1.73	2.57	2.54	2.36	2.16	2.28	2.84	2.00
alpha4	1.51	2.41	2.93	2.63	2.93	2.71	1.95	2.75	1.96	2.92	2.75
alpha5	1.30	1.26	1.20	1.94	1.20	1.23	1.69	2.49	1.48	1.47	1.41
npar1	1.84	1.87	2.00	2.01	2.00	1.97	1.89	1.76	1.83	1.40	1.96
npar2	1.35	1.75	1.98	1.75	1.98	1.59	1.66	1.84	1.55	1.98	1.94
npar3	1.81	1.97	1.94	1.91	1.94	2.03	2.04	1.77	1.93	2.04	1.89
npar4	1.91	2.01	1.79	1.90	1.79	1.63	2.03	1.99	2.04	1.64	2.04
npar5	1.68	1.57	1.96	1.89	1.96	1.94	1.37	1.47	2.02	1.96	1.70
ksat1	7309	3279	3849	8820	3849	8704	9336	8310	4672	9182	4197
ksat2	3075	1441	3728	4270	3729	1211	7658	5264	6679	8930	1275
ksat3	3864	7346	8207	1234	8207	7132	9088	5425	8006	7274	3213
ksat4	5751	2954	4809	9320	4809	9437	8880	7284	2332	4139	5556
ksat5	4327	4573	3420	1068	3420	8965	3964	9379	5090	8734	1125
tort1	1.06	0.67	1.17	0.68	1.17	1.37	0.7	1.37	0.68	1.10	0.54
tort2	0.61	1.05	0.69	0.92	0.69	0.56	0.53	1.01	0.88	0.96	0.55
tort3	1.21	0.63	0.91	1.40	0.91	0.93	0.54	1.07	1.32	0.61	0.61
tort4	0.83	0.69	0.62	0.50	0.62	0.86	1.44	0.69	0.74	1.36	0.55
tort5	0.48	0.77	0.60	1.04	0.60	0.55	0.53	0.94	0.56	0.48	0.84

Table S5 Determined parameter sets for Tharandt plot for the best simulation realted to KGE

	P 1	P 2	P 3	P 4	P 5	P 6	P 7	P 8	P 9	P 10	P 11
infexp	0.45	0.43	0.50	0.57	0.36	0.59	0.28	0.64	0.77	0.68	0.92
betaroot	1.06	1.03	0.96	1.16	1.07	0.90	1.09	1.00	0.95	1.03	0.96
idepth	0.39	1.00	0.45	0.87	0.20	0.20	0.49	0.28	0.36	0.68	0.52
qffc	0.29	0.39	0.48	0.36	0.45	0.064	0.36	0.48	0.35	0.40	0.30
maxrootdepth	-0.83	-0.78	-0.64	-0.63	-0.78	-0.73	-0.50	-0.81	-0.82	-0.72	-0.46
cr	0.69	0.57	0.64	0.55	0.57	0.64	0.58	0.64	0.67	0.56	0.50
ksnvp	0.28	0.19	0.51	0.36	0.51	0.32	0.12	0.99	0.51	0.44	0.89
doybstart	125.2	130.1	122.8	140.1	116.7	138.3	120.9	118.9	113.8	122.3	128.5
cvpd	1.26	0.86	1.57	1.16	1.54	1.76	1.31	0.62	1.97	0.63	1.10
drain	0.20	0.71	0.52	0.13	0.44	0.94	0.20	0.90	0.23	0.60	0.24
length slope	328.6	123.0	44.4	361.6	291.3	466.4	127.5	146.8	163.0	265.0	283.8
ths1	0.27	0.50	0.52	0.59	0.44	0.30	0.24	0.27	0.39	0.26	0.25
ths2	0.35	0.41	0.21	0.24	0.36	0.50	0.22	0.21	0.48	0.37	0.36
ths3	0.52	0.44	0.32	0.41	0.31	0.27	0.29	0.50	0.35	0.59	0.30
ths4	0.49	0.51	0.44	0.60	0.25	0.28	0.31	0.45	0.55	0.42	0.24
ths5	0.56	0.31	0.55	0.51	0.53	0.41	0.32	0.49	0.25	0.37	0.58
thr1	0.028	0.018	0.092	0.055	0.014	0.080	0.014	0.049	0.055	0.032	0.045
thr2	0.017	0.074	0.038	0.040	0.034	0.026	0.043	0.084	0.020	0.049	0.023
thr3	0.033	0.010	0.011	0.042	0.031	0.01	0.021	0.043	0.015	0.038	0.013
thr4	0.11	0.032	0.016	0.12	0.012	0.032	0.027	0.019	0.029	0.18	0.021
thr5	0.063	0.029	0.10	0.18	0.056	0.089	0.039	0.17	0.11	0.12	0.12
alpha1	2.53	2.46	3.67	2.98	2.12	2.73	3.26	3.12	3.50	3.66	3.17
alpha2	2.27	2.72	3.51	3.59	3.66	3.37	3.99	3.47	2.58	2.54	3.12
alpha3	3.75	2.74	3.71	3.82	3.56	3.76	3.66	3.77	2.54	2.65	2.40
alpha4	2.15	3.60	3.33	3.41	2.70	3.90	3.48	3.17	3.03	2.52	3.40
alpha5	2.36	3.41	2.62	3.15	2.64	2.06	3.20	2.87	2.71	2.74	2.13
npar1	1.92	1.56	1.76	1.88	1.74	1.83	1.33	1.63	1.88	1.44	1.99
npar2	1.99	1.43	1.85	1.98	1.78	1.82	1.89	1.87	1.98	1.56	1.94
npar3	1.88	1.75	1.94	1.98	1.86	1.70	1.61	1.89	1.56	1.67	1.85
npar4	1.59	1.35	1.69	1.47	1.68	1.66	1.84	1.66	1.41	1.39	1.70
npar5	1.46	1.93	1.31	1.73	1.78	1.99	1.85	1.54	1.36	1.73	1.69
ksat1	6764	3221	7935	8397	8626	5046	5434	370	1744	6215	7509
ksat2	5382	2268	8028	5559	6042	6433	8152	450	8840	9185	7649
ksat3	4822	7597	2874	8650	4265	658	8820	8617	3081	4543	8442
ksat4	3465	5083	8472	1163	4651	5160	3772	3755	5979	6631	7850
ksat5	6336	7792	6263	3256	996	9923	5516	3484	602	5601	7114
tort1	0.61	0.68	1.19	1.20	0.51	1.11	0.82	0.56	0.98	0.61	1.24
tort2	1.14	0.54	1.43	0.55	1.13	0.82	1.36	1.05	0.83	1.37	1.11
tort3	1.18	1.23	0.56	0.61	1.25	0.50	1.47	0.73	1.05	1.12	0.79
tort4	1.48	1.09	1.38	0.78	0.71	0.51	0.67	0.58	0.96	0.64	1.40
tort5	1.07	1.21	0.71	1.04	1.44	1.23	1.28	1.50	1.37	0.60	0.54